THE FABRICATION AND CALIBRATION OF AN EVAPORATED LUMINESCENT SCREEN FOR APPLICATION IN A MÜLLER-TYPE FIELD EMISSION MICROSCOPE

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

THE FABRICATION AND CALIBRATION OF AN EVAPORATED LUMINESCENT SCREEN FOR APPLICATION IN A MÜLLER-TYPE FIELD EMISSION MICROSCOPE

INTRODUCTION

Until recently, luminescent screens were made by depositing a multitude of tiny crystals 5 to 15 microns in diameter as a uniform layer on a substrate (16, p. 162). These screens, usually about 2 to 10 average crystal diameters thick, then comprise randomly oriented tiny crystals of irregular size and shape. Thereby the screens have unavoidable variations in texture. Electrons incident on these screens at different places have different probabilities of (1) being reflected backwards without transmission through any crystal; (2) being reflected backwards with a variable amount of transmission through one or more crystals; (3) passing through the screens by multiple reflections, without transmission through any crystal; (4) passing through the screens without striking any crystals; and (5) passing through the screen by variable combinations of internal scattering and reflection, whereby the electron may travel a distance ranging from 0 to many times the thickness of the screen (13, pp. 159-160). Most luminescent materials absorb an appreciable fraction of their own emission, which, along with the scattering of light by

the crystals, accounts for the experimentally observed fact that the bombarded side of the screen is brighter than the unbombarded side.

Because of the foregoing screen structure, light from excited crystals is scattered into adjacent non-excited crystals, thus reducing local contrast. Also, the crystal size and screen thickness determine the resolution of the screen. It is possible to fabricate high resolution screens by using only very small crystals; however, this is accomplished only with very special and difficult techniques.

Perhaps the most fruitful single device for the investigation of phenomena at the surface of a metal is the point field emission microscope invented by E. W. Müller (19, pp. 541-550). Since its conception, this device has applied to the study of coatings of foreign materials on the surface of the point cathode (4, pp. 907-932), (6, pp. 225-279), (18, pp. 668-680), adsorption of gases (5, pp. 153-159), surface migration (4, pp. 907-932), (10, p. 4114), (19, pp. 642-665), crystal structure (3, pp. 1579-1583), (9, pp. 293-303), (17, pp. 541-550), and space charge effects in field emission (2, pp. 45-51). The effectiveness of this instrument depends, however, upon the incorporation of a

medium which converts electron energy into visible light. This is, in general, a luminescent screen. It is apparent that, if one is to obtain a faithful translation of information, the luminescent screen must possess both good resolution and good contrast.

Considering these facts, a luminescent screen which is thin, continuous, and transparent to its own emission is highly desirable. Screens of this type have recently been reported in the literature. The history of this development begins in 1934 when J. H. deBoer (7) reported zinc sulfide screens prepared by evaporation in vacua. Unfortunately they failed to show appreciable luminescence even when a suitable activator was evaporated separately and simultaneously. He found that heat treatment following condensation improved the luminescence but decreased the transparency by promoting grain growth.

It was not until 1947, when F. E. Williams (24, pp. 302-306) demonstrated that commercial manganese-activated zinc fluoride phosphor could be evaporated and condensed in vacuum to form thin transparent films, that interest in this type luminescent screen was revived. Williams found that the efficiency of the evaporated phosphor film was not substantially reduced when compared with the original phosphor. This particular

phosphor, however, has a rather serious disadvantage in that it tends to lose efficiency when subjected to bombardment by high current density electron beams.

F. J. Studer (23, p. 559) found a method of transforming the unstable zinc fluoride films to stable zinc sulfide films which will sustain high intensity electron bombardment without deterioration. The modified film is obtained by first evaporating the manganese-activated zinc fluoride to the desired thickness on a clean glass surface, then bringing the glass to a temperature of 500°C in a stream of hydrogen sulfide for a few minutes. The result is manganese-activated zinc sulfide. The films were observed to remain clear and exhibit luminescence very similar to and nearly as bright as the original zinc fluoride coating.

Still another method for depositing clear, continuous, luminescent films was developed in 1951 by F. J. Studer (23, p. 559). The coatings are produced by allowing a stream of zinc vapor, and the vapor of a suitable activator salt (eg, manganese chloride or zinc chloride) to pass over a heated glass surface (400 to 600°C) in an atmosphere of hydrogen sulfide at a pressure of a few millimeters of mercury. A vapor phase reaction occurs preferentially at the heated glass surface. With a properly

cleaned glass surface a uniform, clear film results.

Studer (23, p. 559) found that manganese chloride vaporized with zinc yields the yellow-orange light emitting manganese-activated zinc sulfide (ZnS:Mn) while the use of zinc chloride as the activator salt yields the blue light emitting zinc-activated sulfide (ZnS:Zn). With double activation, a white light emitting screen is obtained (ie, ZnS:Mn, Zn). The manganese-activated zinc sulfide (ZnS:Mn) is the more efficient screen of the three and has been reported (23, p. 559) to have approximately half the brightness of some of the commercial television phosphors.

L. R. Koller and E. D. Alden (11, pp. 684-685) have studied the light output vs. electron accelerating voltage characteristics of chemically deposited screens 0.1 to 0.45 microns thick. The experiment was conducted in the voltage range 2 to 40 kilovolts (d. c.) at a constant current density of 0.8 microamperes/cm^2. They found that following the initial part of the curve over which the brightness increased as a power of the voltage, there is a considerable range over which the brightness is a linear function of the voltage, after which it passes through a fairly sharp maximum and then decreases. The point at which the relation deviates from a straight line

was interpreted as the voltage at which electrons pass completely through the screen and begin to give up energy to the glass. Using the Thompson-Whiddington relation

$$V_o^2 - V^2 = bx \tag{1}$$

where V_o is the initial energy in electron volts, V is the energy after traveling a distance x, and b is a deceleration factor. Then, since the electrons are scattered in passing through the medium, the beam intensity decreases with depth, and the beam energy is related to the depth of penetration by

$$E = i_o \left[\frac{(V_o^2 - bx)}{V_o^2} \right]^{\frac{1}{2} + \frac{a}{b}} \tag{2}$$

where i_o is the initial electron current and a is the scattering constant defined by

$$\frac{dN}{dx} = \frac{N^a}{V^2} \tag{3}$$

where N is the number of electrons/cc. in the beam. A value of 2.4 was determined for a/b in the case of zinc sulfide. These results indicate a large initial rate of loss of energy for an electron beam passing through the phosphor. Nearly 90% of the initial energy is lost in half the range of the electron.

It has been pointed out (16, p. 165) that these thin, transparent luminescent screens have far superior contrast qualities than the conventional luminescent screens. Because they are thin (ie, from 0.05 to 0.5 microns) one would expect excellent resolution from such a screen.

The fabrication of these thin, transparent, and continuous luminescent screens has been treated only very generally by the above mentioned authors. It is the purpose of this thesis to discuss in detail the fabrication of such screens, by the evaporation and chemical methods, and to ascertain the current density response and voltage response for the latter, with the thought in mind of using them ultimately in a Müller-type field emission microscope where contrast and resolution are of the utmost importance.

EXPERIMENTAL PROCEDURE FOR THE FABRICATION OF THE LUMINESCENT SCREENS

The specific resistivity of luminescent materials is very high; usually of the order of 10^8 ohm-cm. or higher (13, p. 390). During cathodoluminescence (ie, luminescence excited by electron bombardment) the absorbed primary electrons tend to charge the screen negatively, so the screen must lose by conduction or emission at least an equal number of electrons. If the screen is bombarded by primary electrons capable of exacting a yield greater than one secondary electron per primary electron, and a collecting field is at hand, the bombarded area will receive the electrons in a stable manner. If the energy of the primary electrons is such that the secondary electron yield per primary electron is less than unity, the bombarded area will become more and more negative until it either reaches cathode potential, thus preventing electrons from reaching it, or else it reaches a potential such that the secondary emission ratio becomes unity.

It is well known that materials used as luminescent screens exhibit secondary emission vs. accelerating voltage curves similar to that in Fig. 1 (1, p. 63). The secondary emission

ratio of the screen rises to a first unity value at about 50 to 200 volts, reaches a maximum from 300 to 800 volts, then falls to a second unity value anywhere from 1000 to 60,000 volts (13, p. 435). The specific unity and maxima values depend strongly upon the chemical composition of the screen, its surface condition (ie, degree of surface contamination), previous treatment such as method of manufacture, and manner of application to the substrate.

Curve (a) of Fig. 2 (1, p. 236) illustrates the operation of an ordinary luminescent screen. The light output is practically zero for primary electron energies less than the first unity value. After this energy has been reached, the light output increases linearly with voltage until a value in the proximity of the second unity value is reached. At this point the curve breaks over and begins to level off. As one proceeds to higher and higher voltages the light output of the screen is not increased since the effective bombarding voltage available for excitation of the screen is just equal to the second unity value. The particular voltage at which the light output vs. accelerating voltage curve breaks over is generally called the "sticking potential". The dotted line (b) above the break-point is an extrapolation of the linear portion of curve (a), ie, this

is the curve for an "ideal" screen. The sticking potential for willemite and zinc sulfide varies from 2000 to 8000 volts, depending on the exact preparation (26, p. 89). For Pyrex glass, such as is used in the electron tube industry, the sticking potential is found to lie between 2000 and 3000 volts (26, p. 89).

Since there is no definite knowledge, within these limits, as to where the sticking potential effect will occur, it is highly desirable to resort to some technique of eliminating or at least minimizing this effect. A method which has been used successfully for a number of years is the deposition of a thin metal film, which can be maintained at a known potential, on the bombarded side of the luminescent screen. This film, of course, must be thin enough so as to cause negligible electron absorption. Also, it must not react chemically with the luminescent material. These requirements are adequately satisfied by aluminum.

Longini (14, pp. 181-182) has published curves which give the percentage of incident electrons transmitted as a function of primary voltage, and the percentage of incident energy transmitted as a function of primary voltage, for aluminum film thicknesses ranging from 500 to 3000 A. Using the information

given by these curves, it is possible to correct the light output vs. accelerating voltage and the light output vs. current density data for the presence of the aluminum backing. Curve (c) of Fig. 2 is a qualitative representation of the influence of such an aluminum backing on the light output of a luminescent screen. It can be seen that the non-aluminized screen is more efficient at low voltages, but once the transmissivity of the aluminum backing reaches a significant value the light output from the aluminized screen soon exceeds that of the non-aluminized screen. This results from the fact that the aluminum also serves as a mirror, reflecting light emitted out the back side of the screen in the forward direction.

In order to most effectively demonstrate the qualities of the thin, continuous luminescent screens, they are compared, side by side, in the same experimental tube, with a screen fabricated from the well known conventional powdered willemite (Appendix C, item 27). For the reasons mentioned previously it is necessary that the screens be aluminized.

Construction of the Screen Carriers

Samples of the transparent luminescent screens are

deposited on Pyrex glass plates (hereafter called screen carriers). These screen carriers are constructed as follows: The rectangular 13 mm by 30 mm by 3 mm Pyrex plates are cut from Pyrex sheet glass (Appendix C, item 1). Next, one end of a 15 mm piece of 50 mil tungsten wire is beaded with uranium glass (see Fig. 3a). This beaded tungsten wire is sealed to one end of the Pyrex plate as illustrated in Fig. 3b, and then each of the screen carriers is annealed to relieve strains. The tungsten oxidizes during the annealing process and must be cleaned by an electrolytic etch in a 1 normal sodium hydroxide solution. The screen carrier is carefully washed with Alconox (Appendix C, item 2) and water, and then permitted to dry.

Since an ordinary evaporated aluminum film will not make satisfactory electrical contact where the glass meets tungsten, it is necessary to employ a special silver paint (Appendix C, item 3) to insure continuity. This paint contains salts of silver which reduce to metallic silver when heated. This paint is brushed onto the periphery of the screen carrier (see Fig. 3c) and also onto the clean tungsten wire. Upon heating the painted screen carriers in air at 550°C for approximately twenty minutes, a conducting metallic band is

formed about the perimeter of the glass which makes good electrical contact to the tungsten wire as well as presenting a large area for electrical contact with the subsequently evaporated aluminum film.

It is very important that the screen carriers be clean (ie, free of finger prints, etc.) if uniform screens are to be expected. A successful method of cleaning is as follows: Immediately after the silver paint is fired into the glass, the glass surfaces are carefully washed with a detergent (eg, Tide) (Appendix C, item 4) then with the special detergent Alconox. Following this they are rinsed in distilled water, then dipped for two minutes in a two percent solution of hydrofluoric acid. They are once more rinsed in distilled water and then permitted to dry in a dust free atmosphere.

Preparation of the Willemite Screen

On one of these cleaned screen carriers is deposited a conventional powdered luminescent screen. Willemite (Zn_2SiO_4:Mn3%) was chosen for this purpose since its characteristics have been widely studied (15, pp. 116-127), (20, pp. 73-83), (21, pp. 383-391) and also because it is the standard material

used in field emission studies.

The screen is fabricated using the lacquer flow technique. This method gives a surface density of phosphor of 1 mg/cm^2. The lacquer formula and technique of application is described in Appendix A. After the lacquer (containing the phosphor) has dried the nitrocellulose component is removed by baking in air at a temperature of 500°C for ten to fifteen minutes. After cooling, the unwanted phosphor material may be scraped off quite easily with a clean cloth.

It has been found that in order to obtain a conducting metal film on the back of such a powder screen which is thin enough so as to cause negligible electron absorption in the voltage range above 5000 volts, it is necessary first to cover the screen with a thin nitrocellulose blanket commonly referred to as a "metal carrier". This is accomplished by immersing the screen carrier in a small dish, approximately one inch deep, filled with a 10% acetone-90% distilled water solution. A few drops (10^{-3} cc/cm^2 of water area) of the metal-carrier (Appendix C, item 5) are placed on the surface of the water-acetone solution with an eyedropper. These drops immediately spread out into a uniform, thin film (approximately 1000 A thick). The presence of the acetone in the

distilled water permits the metal-carrier to spread over the surface with greater ease and rapidity. The film is permitted to harden for four minutes, then the screen carrier is carefully raised, screen up, through the surface by means of a small wire slipped over the 50 mil tungsten wire of the screen carrier. This is done slowly, care being taken not to jerk since the metal-carrier is very fragile. The screen is permitted to dry in a dust free atmosphere. After about an hour the screen may be examined for breaks in the metal-carrier. A break will appear quite dull as compared to the satiny sheen exhibited by the remaining portion of the film. It is necessary that the screen be examined before it is completely dry since it is virtually impossible to determine the broken areas later. The screen should be permitted to dry overnight before the metal is applied. The drying time may be shortened by oven heating to 100° C or so.

The aluminum is evaporated onto the screen by means of a 6-turn spiral filament of 20 mil tungsten wire which is formed on a 6-32 machine screw. The pitch is increased slightly by stretching the spiral after removal from the screw. A small slug of aluminum wire is constructed to fit snugly into the spiral filament and the whole assembly is given a short

electrolytic etch in a 1 normal sodium hydroxide solution to remove the aluminum oxide from the slug and the tungsten oxide from the filament. If this is not done, the aluminum must break through the sack-like enclosure of aluminum oxide surrounding it before evaporation occurs. Removal of the aluminum oxide makes the evaporated aluminum film much more uniform and easier to control as well as assurring that particles of aluminum oxide do not land on the screen when the aluminum oxide sack is broken.

The spiral filament is weighed with a very sensitive balance and then mounted on conducting leads through a metal table on the vacuum system (see Fig. 4a; construction details are discussed in Appendix B). The screen carrier is placed (screen down) 10 cm above the evaporation filament in the manner shown in Fig. 4b. A bell jar is placed over the entire unit and evacuated. The vacuum system consists of a mechanical forepump and a mercury diffusion pump with liquid air traps. Outgassing is begun when the pressure in the bell jar is about 5×10^{-4} mm Hg. The aluminum slug and tungsten filament are outgassed by flashing the tungsten to very high temperatures (approximately 1800°C) for very short periods of time. Evaporation is begun when the

pressure no longer decreases below 5×10^{-4} mm Hg. when the melting temperature of aluminum is reached. This temperature is maintained until the desired thickness of aluminum is deposited. After evaporation the filament is again weighed The thickness of the aluminum film may then be computed, using the formula (22, p. 177)

$$t = \frac{m}{4\pi\sigma\rho^2} \qquad (4)$$

where m is the weight in grams of aluminum evaporated, σ is the density of the aluminum in gm/cc, p is the distance between the filament and screen in cm, and t is the thickness of the evaporated film in cm.

After the screen is aluminized the metal-carrier is removed by baking the screen carrier in air starting at room temperature and coming up to 350°C at the rate of temperature increase of approximately 300°C/hour. Baking is then continued for thirty minutes. The aluminized willemite luminescent screen is now complete and ready for use.

Preparation of the Evaporated Manganese-Activated Zinc Sulfide Screen

It is very difficult to evaporate a material which is in powder

form. The usual method of preparing the specimen for evaporation is to form a small solid briquette by means of a hydraulic press. If such a press is not available, the following alternative technique which is high successful may be used.

Several grams of the manganese-activated zinc fluoride phosphor (Appendix C, item 6) are placed in the bottom of a Pyrex test tube (6 inches long, 2 inches in diameter). A cork stopper fitted with gas inlet and outlet tubes and a conventional two-wire inseal, onto which is spotwelded a 20 mil 6-turn tungsten spiral filament, is inserted in the top of the test tube as illustrated in Fig. 5. The two-wire inseal may be raised or lowered at will by simply pulling it up or pushing it down. The gas outlet tube is connected to a 500 ml. Ehrlenmeyer flask by means of rubber tubing. The stopper in this flask is fashioned of Pyrex glass wool in order to absorb particles of the zinc fluoride phosphor which are blown out of the first vessel by the gas. This is necessary because the zinc fluoride phosphor is toxic, the extent of which has not definitely been established. Argon gas is admitted in a steady stream. After a few minutes the tungsten filament is heated

to approximately 1500°C and lowered into the phosphor powder for two minutes. A large globule (approximately 1/4 cc) of molten phosphor is formed. This globule does not generally adhere to the tungsten filament when cooled, or if it does, it can be broken off very easily. Upon removal one finds that the powdered phosphor adheres to the solidified globule so this must be scrapped off (see Fig. 6a; shown also is a centimeter scale). The globule is then broken into sizes suitable for subsequent evaporation.

A tungsten filament is a very satisfactory evaporation source. The filament is fabricated of 20 mil tungsten wire wound into a 6-turn helix (constructed in the same way as for the aluminum evaporation discussed previously). The tungsten filament is subjected to a brief electrolytic etch in a 1 normal sodium hydroxide solution to remove the tungsten oxide, after which it is carefully rinsed and dried. The small bits of phosphor are then inserted in the tungsten helix (see Fig. 6b; shown also is a centimeter scale) and the completed filament and phosphor unit is then weighed on a sensitive balance. The remaining procedure is quite similar to that employed in the evaporation of aluminum. The phosphor-laden tungsten filament is mounted on the conducting leads of the

metal vacuum table (as in Fig. 4b). The clean screen carrier is positioned 10 cm above the filament (as in Fig. 4b). A bell jar is placed over the entire unit and evacuated by the mercury diffusion pump system previously mentioned. The bell jar section of the system is "leak chased" with an induction coil to further clean the glass surface. Adsorbed water vapor is removed in this manner. When the pressure in the bell jar is reduced to approximately 5×10^{-4} mm Hg., the tungsten filament is heated slowly to permit the filament as well as the phosphor to outgas. After several minutes of this it is advisable to momentarily "flash" the filament to temperatures of approximately 1800°C. This is repeated every 15 seconds or so. The outgassing procedure is continued until the filament temperature may be increased, without increasing the pressure, to the level where the phosphor adjacent the filament begins to melt. The temperature of the filament is adjusted such that only the phosphor adjacent to the filament melts. If the temperature is too high the gas released will cause large fragments of the phosphor to be thrown off. The evaporation process requires anywhere from 15 minutes to an hour, depending on the film thickness desired.

When the evaporation is complete the filament is again weighed and the condensed film thickness computed from formula (4).

Following the procedure of F. J. Studer (23, p. 559) the manganese-activated zinc fluoride is converted to stable manganese-activated zinc sulfide by placing the screen in a Pyrex tube surrounded by an oven (details of the oven arrangement are discussed in the next section). Provision is made for a controlled flow of hydrogen sulfide. The screen is raised to 500°C before the hydrogen sulfide is admitted. The screen is maintained at a temperature of 500°C in the hydrogen sulfide atmosphere (at 5 mm Hg. pressure) for 10 minutes.

Phosphor covering the silver band may be removed by rubbing with a small piece of fine steel wool. This is necessary to insure good electrical contact to the subsequently evaporated aluminum film. Since this luminescent screen is in the form of a thin, continuous sheet, it is not necessary to cover the screen with a metal-carrier before aluminizing. The aluminum film is deposited and its thickness determined in the usual manner.

Preparation of the Luminescent Screens Formed by Vapor Phase Reaction

The process of vapor phase deposition requires an oven capable of temperatures as high as 550°C, a source of hydrogen sulfide, a pressure manometer, and a vacuum pump. The complete arrangement is illustrated in Fig. 7 and Fig. 8.

The oven is a rectangular box 16 inches by 12 inches by 9 inches constructed of 2 inch Kaylo (Appendix C, item 7). The heating elements, H, are 1/2 inch helical coils of #18 Chromel A resistance wire, and are mounted on three sides of the interior. The total resistance of these elements is 8.5 ohms. A power input of 1000 watts brings this oven from room temperature to 550°C in about 15 minutes, whereas a power input of 700 watts is sufficient to maintain the oven temperature at 550°C. The oven temperature is measured with a special high temperature mercury thermometer, T_2, whose range is 0°C to 675°C (Appendix C, item 8).

Since the process requires an hydrogen sulfide atmosphere, the necessary chemicals and clean screen carrier are placed in a 50 mm diameter Pyrex tube, vessel V in Fig. 7 (hereafter referred to as vessel V), 18 inches in length. Approximately

half the length of this vessel is inserted into the oven through an opening in its side (see Fig. 7 and Fig. 8). A rubber stopper, R, fitted with two 8 mm diameter Pyrex tubes serves to seal the open end. In order to assure a sufficiently good vacuum seal the diameter of the 8 mm tubing is increased to approximately 11 mm just outside the rubber stopper. In this way atmospheric pressure aids in securing a good vacuum seal when vessel V is evacuated. One of these 8 mm tubes, G_1, reaches almost the full length of vessel V. This tube serves as the gas inlet tube. The second, the gas exhaust tube, G_2, extends only a few inches into the vessel V. The screen carrier, S, is fastened near the end of the gas inlet tube by means of a 20-mil platinum wire helix, P, which fits around the 50 mil tungsten wire of the screen carrier.

The chemical holder, C, is a Pyrex dish two inches long and one fourth inch deep at the center (see Fig. 7). This dish is positioned just forward of the screen carrier in the vessel V.

It is necessary to use a vacuum wax (Appendix C, item 9) in order to achieve a sufficiently good vacuum seal around the rubber stopper. Ordinary household aluminum foil, A, serves quite satisfactorily as a radiation shield to prevent this wax

from becoming too hot. Also, since heat conduction is a problem, the outside of the vessel V near the stopper is cooled by wrapping a few turns of 1/2 inch thin wall rubber tubing, W, about it and circulating a steady stream of cold water through the coils. No decomposition of the wax results if this combination of radiation shielding and water cooling is employed.

A commercial "D" cylinder, G, containing 4 pounds 1 ounce of hydrogen sulfide (Appendix C, item 10) serves as the hydrogen sulfide source. The hydrogen sulfide in the cylinder is in liquid form (its maximum pressure is 260 pounds/inch^2 at 70°F), therefore a high pressure regulator valve is not necessary. A special needle valve, N, for use with corrosive gases is manufactured by Hoke (Appendix C, item 11). This needle valve is fastened directly to the yoke adaptor of the hydrogen sulfide cylinder. If such a needle valve is not available a simple pinch clamp will serve satisfactorily if a piece of 20 or 30 mil wire is first inserted in the rubber tubing where it is to be pinched down by the clamp. Either of these variable leaks performs well, but the needle valve is more convenient.

As mentioned above, hydrogen sulfide is corrosive, especially in the presence of water vapor. Thus, for economic reasons, an expensive vacuum pump is not recommended. A Cenco Pressovac, E, (Appendix C, item 12) will maintain the proper pressure in the tube with no difficulty (ie, one mm Hg. or less residual pressure).

The pressure in the system is monitored with a simple U-manometer, M. Connection between various pieces of apparatus is made with heavy wall rubber tubing, T_1.

Hydrogen sulfide is toxic as well as corrosive, therefore it is extremely important that the entire system be located under an exhaust hood, with the vacuum pump located out-of-doors.

The chemicals required are analytical reagent grade granular zinc metal (30 mesh) and analytical reagent grade manganese chloride ($MnCl_2 \quad 4H_2O$) (Appendix C, item 13).

Approximately two grams of zinc metal and 1/4 to 1/2 gram of the activator salt, manganese chloride, are placed in the Pyrex chemical holder. The chemical holder is then placed in the far end of the vessel V. The clean screen carrier is slipped into the platinum wire helix and the rubber stopper assembly inserted in the vessel V as illustrated in Fig. 7. The temperature

of vessel V is increased at the rate of 300°C/hour for the first twenty minutes. A higher rate of increase results in violent sputtering of the activator salt because it contains water. This is undesirable only in that some of these bits of activator material strike the screen carrier and adhere to it. After the initial twenty minutes, the temperature is increased at the rate of 1200°C/hour. When the temperature 550°C is reached the needle valve controlling the gas flow is adjusted such that the pressure in the vessel V is 5 mm Hg. (there is a residual pressure of 1 mm Hg.). Under these conditions the reaction proceeds at a rate such that approximately 800 A of luminescent material is deposited per hour. The thickness is judged by observing the color of the light produced by interference in the thin film. The resulting films, in general, appear quite uniform and clear.

Unlike the case of evaporation in high vacuum where the luminescent material is deposited only on one side of the screen carrier, here the material is deposited on both sides. The unwanted portion may be scraped off with a fine grade of steel wool. Also, it is advisable to scrape the silver band on the film side of the screen carrier to assure good electrical contact to the subsequently evaporated aluminum backing. As in the case

of the screen formed by evaporation in high vacuum, the aluminum film is deposited directly onto the screen in the manner previously described.

DETAILS OF THE EXPERIMENTAL PROCEDURE FOR DETERMINING THE PROPERTIES OF THE LUMINESCENT SCREENS

One of the principal problems is to compare the light output of the thin, transparent luminescent screens with the known powder luminescent screen fabricated of willemite as the incident energy of the electrons and the electron density is varied.

Essential to this study are; (1) a demountable vacuum tube in which the experimental screens may be supported; (2) a source of electrons, ie, an electron gun; (3) voltage sources for electron gun operation as well as for the screens; (4) a vacuum system capable of pressures of the order of 10^{-5} mm Hg.; (5) a photomultiplier tube to measure the light emitted by the screens; (6) a low power, calibrated microscope for determining the size of the excited area; (7) a sensitive current meter for measuring the current incident on the screens; and (8) a voltmeter to measure the potential of the experimental screens.

Construction of the First Experimental Tube

The first experimental tube (hereafter referred to as Tube 1)

is composed of three basic units: the main body of the envelope (1); the electron gun (2); and the screen carrier support and observation window (3). Figure 9 is a scale cross-sectional drawing of Tube 1. The three basic units of Tube 1 are joined together with Pliecene vacuum wax (Appendix C, item 14) so that the replacement of any one unit requires a minimum of time and effort.

Unit (1) is constructed of 56 mm diameter Pyrex tubing. A narrow, shallow, constriction one inch from the front end of unit (1) is necessary to prevent slipping of unit (3) when the completed envelope is evacuated thus breaking the wax seal. The other end of unit (1) is reduced in diameter so that the electron gun unit (2) is a snug fit. Here also, a narrow constriction is necessary to prevent slipping.

A single wire "button seal", B, is sealed on just ahead of the exhaust tube, E. The purpose of this button seal is to make electrical contact to the second anode of the electron gun. Immediately after the button seal is fused on, unit (1) is annealed in an annealing oven. The tungsten wire in the button seal is etched in a 1 normal sodium hydroxide solution to clean off the layer of oxide. The sodium hydroxide is rinsed out and the glass cleaned by washing with the detergent, Alconox, and finally

rinsing several times with distilled water. After drying, a band of silver 1/4 inch wide is fired into the glass including the button seal. This is done to present a large area for electrical contact to the Aquadag (Appendix C, item 15) which is next painted on the interior of unit (1). After painting, unit (1) is placed in an oven and heated to approximately 100°C to remove water vapor from the Aquadag. The Aquadag film serves as the second anode of the electron gun.

The thermionic gun from a 5FP7 magnetically focused cathode ray tube (C.R.T.) is used as the electron source. This C.R.T. and its focusing coil (D.C. resistance; 70k) were salvaged from a war surplus ID-19/APS-3 Radar Indicator. Extreme care must be taken when"breaking open" an evacuated glass envelope of this size. The most satisfactory method is to remove the base of the tube thus exposing the seal-off stem. The envelope is placed behind a screen and the end of the seal-off stem cracked off with a pair of pliers. If care is taken it is possible to let air in at a fairly slow rate. The gun section is separated from the remainder of the envelope by cutting with a "hot-wire" glass cutter. The tip of the seal-off stem is carefully fused together, and the base replaced. To avoid the necessity of using a graded seal to fuse the soft glass

of the C. R. T. envelope to the Pyrex of unit (1), the two units are joined with Pliecene vacuum wax. Alignment of the gun is important so it must be done carefully.

Figure 10 is a photograph of a relatively crude focusing coil support. This support permits the three principal degrees of motion, plus a rotation about an axis normal to the top of the vacuum system.

Unit (3), in which the experimental screens, S, are to be mounted, is constructed of 51 mm diameter Pyrex tubing. This tubing is a snug fit in the 56 mm diameter tubing of unit (1). To facilitate the rapid replacement of screen samples, the inseal, I, on which the screen carriers are to be mounted is sealed into the female member of a 40/50 taper ground joint. The male member is sealed to the 51 mm tubing, the seal being roughly elliptical in cross-section in order to place the screen samples as close to the face of the tube as possible. Following this, the 51 mm tubing is cut off (with a glass saw) at the very edge of this seal and a flat Pyrex disk (50 mm diameter, 3 mm thick) is sealed over the end. This is done to present a flat, distortionless window through which photographs, light measurements, and area measurements can be made.

The length of the 50 mil tungsten lead-in wires is extended by spotwelding additional lengths of 40 mil tantalum wire to them. The length is adjusted such that the screen carriers, subsequently fastened on by spotwelding, will be centered, side by side, in the 51 mm tubing (see front view in Fig. 9).

Unit (3) is joined to unit (1) with Pliecene wax and the completed structure sealed to the vacuum system. Figure 11 illustrates the mounting of Tube 1 on this vacuum system.

Electrical Circuitry for Tube 1

Figure 12 presents a schematic of the electrical circuitry associated with Tube 1. The cathode heater, H, is powered by a power supply, V_1 (Appendix C, item 16), as is the focusing coil, M. The voltage on the first anode, A_1, is supplied from power supply V_2 (Appendix C, item 16). A small 45 volt battery serves to bias the grid, G, a negative 45 volts. The second anode, A_2, is supplied by a 0 to 10 kv power supply, V_3.

The screen potential which is to be varied at will is supplied by a 0-25 kv power unit, V_4. The current incident upon the screens is measured by inserting the microammeter, I (Appendix C, item 17), between the power unit V_4 and ground.

In this way the case of the current meter is at ground potential. The potential of the screens, S, is measured with the voltmeter, M_1 (Appendix C, item 18). The potential of A_2 is maintained at 3 kv. Thus, in order to obtain reliable current readings, the potential of the screens cannot be less than 3 kv, otherwise secondary electrons ejected at the screen by incident primary electrons would be collected by A_2. All of the power supply units are tied to a common ground (remembering that V_4 is grounded through I).

The electron beam is deflected from one screen to the other by means of a small horseshoe magnet mounted on a long polystyrene rod, which, in turn, is clamped in such a way that it can be rotated through a small horizontal arc near the tube. Since the deflection of the beam is small (approximately 1/2 inch) the cross-sectional area of the beam is assumed not to have been altered in this operation.

A defective ground connection on power supply V_3 was responsible for an arc discharge between the second anode A_2, and the screen S (Fig. 11) which eventually resulted in the destruction of the thermal cathode, C. The nearness of the second anode to the screens, and difficulties in attaining spot

sizes of a millimeter or so in diameter, prompted the construction of a second experimental tube employing an electrostatic electron gun.

Construction of the Second Experimental Tube

Figure 13 is a scale cross-sectional drawing of the second experimental tube (hereafter referred to as Tube 2). This tube, like Tube 1, is composed of three basic units: the main body of the envelope (1); the electron source (2); and the screen carrier mount and observation window (3).

Unit (1) is constructed of 56 mm diameter Pyrex tubing such that the second anode, A_2, is located a considerable distance from the screens, S, so that a greater difference in potentials may be used without danger of electrical breakdown. The shape of the second anode, A_2, is so chosen to shield its edge from the screens as much as possible. Silver paint is used for the second anode because it has a higher electrical conductivity than Aquadag. The cleaning and firing techniques have been described previously.

An electron gun from a 5BP1 C.R.T. was chosen because a complete power supply was available for such a tube. A 5BP1

C.R.T. is employed in a war surplus ASB-7A, CJP-55AER Radar Indicator. This unit is easily converted to 60 cycle operation by simply replacing the 400 cycle 6.3 volt filament transformer with a 60 cycle transformer insulated for at least 2500 volts since the cathode is operated at a negative 2050 volts. This is fortunate, since if the voltage difference between the second anode, A_2, and the screens, S, is 5000 volts, then the electrons incident on the screens possess approximately 7000 electron volts of energy.

This C.R.T. was "broken open" in the manner previously described, and the gun portion of the envelope severed from the remainder of the tube with a "hot-wire" glass cutter. The glass in this tube is much thicker than that of the 5FP7, consequently it is important that it be heated much more slowly when the electron gun unit (2) is waxed to unit (1). The gun unit is positioned in unit (1) so that the deflection plates will be horizontal and vertical when the completed envelope is sealed to the vacuum system.

Unit (3) was salvaged intact from Tube 1 and waxed into place in unit (1). The completed envelope was sealed onto

the vacuum system.

An extension cable was constructed so that the voltages for the electron gun electrodes and cathode heater could be taken directly from the ASB-7A Indicator unit and its associated power supply. The advantage of this, of course, is that the spot diameter, beam current, and spot position may be varied using the controls in the Indicator unit.

Figure 14 is a photograph of Tube 2 mounted on the vacuum system. Because of a small misalignment in wax sealing the gun unit it was necessary to use the small horseshoe magnet, M, to center the beam on the screen, S. When this was done the beam could be deflected from one screen to the other with the horizontal positioning control on the Indicator unit.

Electrical Circuitry for Tube 2

The electrical circuitry associated with Tube 2 is presented schematically in Fig. 15. The indicated voltages on the electron gun electrodes are cabled directly from the Indicator unit. The screen potential is maintained by a power supply, V, which is variable from 0 to 25 kv. As with Tube 1, the incident electron current is measured by inserting

the microammeter, I (Appendix C, item 17) between the power supply V and ground. The potential on the screens is measured with the voltmeter, M (Appendix C, item 18).

The Vacuum System

The vacuum system is pictured in Fig. 16. A simple U-trap, T, is installed in the vacuum line between the experimental tube, Tube 1, and the diffusion pump, D. During operation, this U-trap is immersed in a Dewar flask containing liquid air. The Eimac HV-1 oil diffusion pump, D (Appendix C, item 19) is connected to the Cenco Megavac forepump, F (Appendix C, item 20) by means of heavy walled rubber tubing.

The pressure on the high-vacuum side of the diffusion pump and cold trap is monitored with a Phillips type vacuum gauge, G (Appendix C, item 21).

Evacuation Procedure

The screen carriers, S, are spotwelded to the inseal, I (see Fig. 9). The ground joint is smeared with Apiezon "L" vacuum grease (Appendix C, item 22) and the joint put together. The pumps are started and the U-trap is immersed

in liquid air. Cathode outgassing is begun when the Phillips gauge registers 10^{-4} mm Hg. The filament is heated until the pressure increases to 10^{-3} mm Hg., then turned off. This procedure is continued until the pressure no longer increases when the filament is heated. The ultimate pressure with the cathode hot is 3×10^{-5} mm Hg. No attempt is made to outgas other components of the electron gun. The ultimate pressure with the cathode cold is 1×10^{-5} mm Hg., and is attained with approximately three hours of pumping.

Spot-Size Measurement

The spot-size (ie, dimensions of the excited area) is measured with a low power microscope (Appendix C, item 23) which has a calibrated 12.5x ocular and a 1x objective. Figure 17 shows the microscope in position for a measurement. All area measurements are made on the transparent screen because of its superior resolution.

The beam has an elliptical cross-section (see Fig. 21) so the area of the excited region is obtained by using the measurements of the major and minor axes and the formula

for the area of an ellipse,

$$A = \pi a b \tag{5}$$

where a is the semi-major axis and b is the semi-minor axis.

Light Measurement

Figure 18 is a schematic of the electrical circuitry associated with the light measuring apparatus. The light is measured with a 931-A photo-multiplier tube (Appendix C, item 24). The photo-multiplier is housed in a light tight copper can (P of Fig. 18 and Fig. 19) 2-1/8 inches in diameter and 5-1/2 inches high. A 1 inch copper tube, 3-1/2 inches long, is soldered to the can. In this is inserted a 6-1/2 inch polystyrene rod wrapped with black plastic electricians tape. This rod is tapered so that the probe aperature is 1/8 inch in diameter. Voltage for the dynodes of the photo-multiplier is supplied by power supply, V_1.

The output of the photo-multiplier is connected to ground through a 7 megohm resistor. The voltage across the resistor, R, is monitored with a vacuum tube voltmeter, V

(Appendix C, item 27). In order to avoid calibration of the photo-multiplier and vacuum tube voltmeter, the light input to the photo-multiplier is limited to a constant value. This is accomplished by placing a calibrated photographic density step wedge, W (Appendix C, item 26) in front of the photo-multiplier probe. The step wedge is moved along the front of the probe until a density step is reached such that the meter V records a previously chosen voltage. This voltage is chosen well above the background of the photo-multiplier tube. The light output, L, of the screen may then be determined from the relation

$$D = \log L \qquad (6)$$

The photo-multiplier, P, is mounted on an arm which can be pivoted so as to point at one screen, and then the other (see Fig. 20). The pivot point is on the axis of the experimental tube.

When making light measurements the probe is positioned so as to obtain a maximum reading from the excited area (as in Fig. 19), then the density step wedge is slipped in front of the probe and moved along until the voltmeter records the

previously chosen base voltage. In order to increase the sensitivity of this measurement, a small piece of film of density approximately half the difference between suceeding density steps is used.

Determination of Voltage Response

Figure 20 illustrates the complete assembly of equipment used in the operation of Tube 2 with the exception of power supply V which is located outside the picture, and the microscope.

The voltage response of the thin, transparent screen and the standard willemite screen is determined as follows: The current density is to be maintained at a constant value thus requiring that the spot-size be measured at each voltage point and adjusted to the same constant value. The beam current is independent of the screen potential, but has a tendency to creep upward with time, so it must be adjusted to maintain a constant current density. The background level of the photo-multiplier tube was approximately 1.5 volts (background light from the cathode heater was not sufficient to register on the voltmeter), thus a voltage of 4.0 volts was

chosen as the reference voltage. The probe was adjusted and light values determined in the manner described above. This was repeated for the several voltage points in the desired range. The light output from each screen, for each voltage, is determined from equation (6), which may also be written

$$L = \text{antilog } D, \tag{7}$$

where D is the density of the step required to reduce the light transmitted such that the voltmeter V registered 4.0 volts.

Determination of the Current Density Response

These measurements are made at constant screen potential. In this case the beam current and dimensions of the excited region could be varied at will. The light output from each screen was determined in the manner described above.

DISCUSSION OF EXPERIMENTAL RESULTS AND CONCLUSIONS

For convenience in this discussion, screens prepared by evaporation in high vacuum will be referred to as "prepared by Method I," and those fabricated by vapor phase reaction at the heated glass surface will be referred to as "prepared by Method II".

A visual comparison of the thin, transparent, continuous luminescent manganese-activated zinc sulfide film (prepared by Method II) with the conventional powdered willemite luminescent screen is very striking. Figure 21 illustrates the character of the two screen types when excited by electrons under identical experimental conditions. Both screens were in the same tube (Tube 1). The screen potential was 2500 volts (second anode, A_2 in Fig. 12, was at screen potential) and the current density was 1 microampere/cm^2. The electron beam diameter was identical for both screens (ie, the beam was merely deflected from one screen to the other). Further, the aperture stop of the photographic lens and the exposure time for the two photographs were the same. A halation ring, (12, pp. 512-513, 516-520) absent in the transparent screen, was quite obvious in the powdered screen.

Measurements indicate that the area of the primary spot on the powdered screen is approximately 2.5 times greater than the spot on the transparent screen. The intensity of the light emitted by the powdered screen was approximately 10 times greater than that of the transparent screen. Even when the electron beam intensity was reduced by a factor of 10, a faint halation ring was present in the powdered screen. The presence of a halation ring in the transparent screen was not observed throughout the course of this experiment.

The manner in which the light output varies with incident electron energy for a 1000 A (as computed from the color of the light produced by interference in the thin film) transparent manganese-activated zinc sulfide screen (prepared by Method II) backed with 800 A of aluminum is given by curve C of Fig. 22 (data from Tube 2). When appropriate corrections for losses in the aluminum are made (14, pp. 881-882) curve C acquires the form curve D. The non-linearity of the curve indicates that as the energy of the incident electrons is raised, an increasing percentage of electrons completely penetrate the thin luminescent film and give up a larger fraction of their energy to the glass screen carrier, and at sufficiently large energy the light output actually decreases. Strange and Henderson (21, p. 390)

have established that the light output increases as a first power of the accelerating voltage for a powdered manganese-activated zinc sulfide screen sufficiently thick to completely absorb the incident electrons. Koller and Alden (11, pp. 684-685) have also established this relationship for the thin transparent zinc sulfide films. Data was not obtained at corrected voltages below 3000 because of a limitation imposed by the light measuring technique. As a result, the linear portion of the curve is not well established. If, however, a straight line of unit slope is drawn through the first experimental point of curve D, an estimation of the thickness of the screen can be made using the well known relation (equation (1)), expressing the energy loss of an electron in passing through matter, written in the form (14, p. 882)

$$V^2 = V_0^2 \left(1 - \frac{f X \sigma}{V_0^2}\right), \tag{8}$$

where V_0 is the initial energy of the electron in electron kilovolts, V is the mean electron energy going through $X\sigma$ grams/cm^2 of material, f is approximately 5×10^5 (KV)^2 cm^2/g (relatively independent of material). The "range" of the electrons is

$$X_{max} = \frac{V_0^2}{f\sigma}, \tag{9}$$

where, in this case, V_o is the energy at which the electrons just penetrate the film and begin to give up energy to the glass. This energy corresponds to the point of departure from linearity in curve D. Using that value of V_o and the density, ρ, (13, p. 371) of powdered manganese-activated zinc sulfide, Xmax is approximately 600 angstroms (assuming no electron scattering, ie, that the path Xmax is equal to the screen thickness). This is in reasonable agreement with the thickness calculated by the interference method mentioned previously.

The thickness of the aluminum backing on the willemite screen was estimated at approximately 1000 A, using equation (4). However, the screen and aluminum were subjected to an air bake at 350°C for an hour to remove the nitrocellulose metal carrier. As a result the aluminum film thickness may have been changed.

Using the established (20, p. 79) voltage squared dependence of light output from willemite it is a simple matter to determine the aluminum film thickness. Longini's figures for 800 A of aluminum (interpolated values) yield an initial slope of two when applied to the original data. This is the figure used in subsequent corrections of the light output area vs. current density data.

The wavelength of the light emitted by the thin manganese-activated zinc sulfide was estimated at approximately 6000 A. Willemite is known to peak at approximately 5250 A (13, p. 255). The R. C. A. 931-A photo-multiplier has ten times greater sensitivity at 5200 A than at 6000 A. This variation of sensitivity with wavelength of light of the photo-multiplier has been taken into consideration in plotting this and subsequent data.

Figure 23 presents a comparison of the light output/unit area vs. current density data from the powdered willemite screen and the transparent screen discussed above, for 5000 electron volts (uncorrected) incident electron energy.

Curves A and C indicate the original data and curves B and D the data corrected for losses in the aluminum. The light output per unit area of willemite is decreased by 20% at a current density of approximately 50 microamperes/cm^2 whereas this same percentage reduction occurs at approximately 70 microamperes/cm^2 in the case of the continuous zinc sulfide screen. The straight line drawn through each set of experimental points is of unit slope.

Figure 24 presents a similar comparison of the behavior of the two types of screens for 7000 electron volts (uncorrected) incident electron energy. A reduction of 20% from the linear

relationship occurs at approximately 100 microamperes/cm^2 for willemite. This is in qualitative agreement with data published by Strange and Henderson (21, p. 386). They indicate that the slope of light output vs. current density curve is strongly dependent upon the activator concentration, the length of the initial linear part increasing with increasing activator concentration. They found that for 2% manganese the curve had a slope of approximately 0.2 at a current density of 250 microamperes/cm^2 and electron energy of 5000 volts and was still greater for 5% manganese. A measurement of the slope of curve B at 250 microamperes yields a value approximately 0.4 (willemite used in this experiment has 3% manganese activator concentration). The larger slope of 250 microamperes for curve B may also be partially explained by the fact that the electron energy in this case is approximately 6000 electron volts.

The extreme length of the linear part of the curve for zinc sulfide is attributed to complete penetration of the phosphor by electrons of this energy. This data indicates that under these conditions the light output is reduced from the predicted value by 20% at approximately 1 ma/cm^2.

Investigation of the behavior of the thin luminescent film prepared by Method I was not possible because of a large crack

which occurred in unit (1) of Tube (2).

A Muller-type field emission microscope employing such a screen had previously been constructed. Its threshold operation (ie, voltage and current for a just visible pattern) was compared with that of the conventional Muller-type microscope (similar cathode geometries) (8, pp. 1043-1054). The transparent screen was approximately one-tenth as efficient as the willemite. It is interesting to note, however, that the emitted light was almost white. Adverse vacuum conditions prevented photography of the emission pattern.

The relative efficiencies of the thin, transparent luminescent screens in this investigation were lower than similar screens reported in the literature (23, p. 559), (24, p. 305). A careful variation of the hydrogen sulfide pressure and oven temperature in Method II may lead to an optimum efficiency.

Although the relative efficiencies of the thin, transparent screens may be an order of magnitude less than conventional powder screens, this is not a serious limitation since very high brightness is required only when the contrast qualities are poor.

If large surfaces of simple geometry are to be coated with a thin transparent luminescent screen, Method I is generally

most convenient. Method II is particularly suited to coating surfaces of irregular shape. Also Method II permits greater freedom in choosing general spectral distribution (ie, by choice of activator).

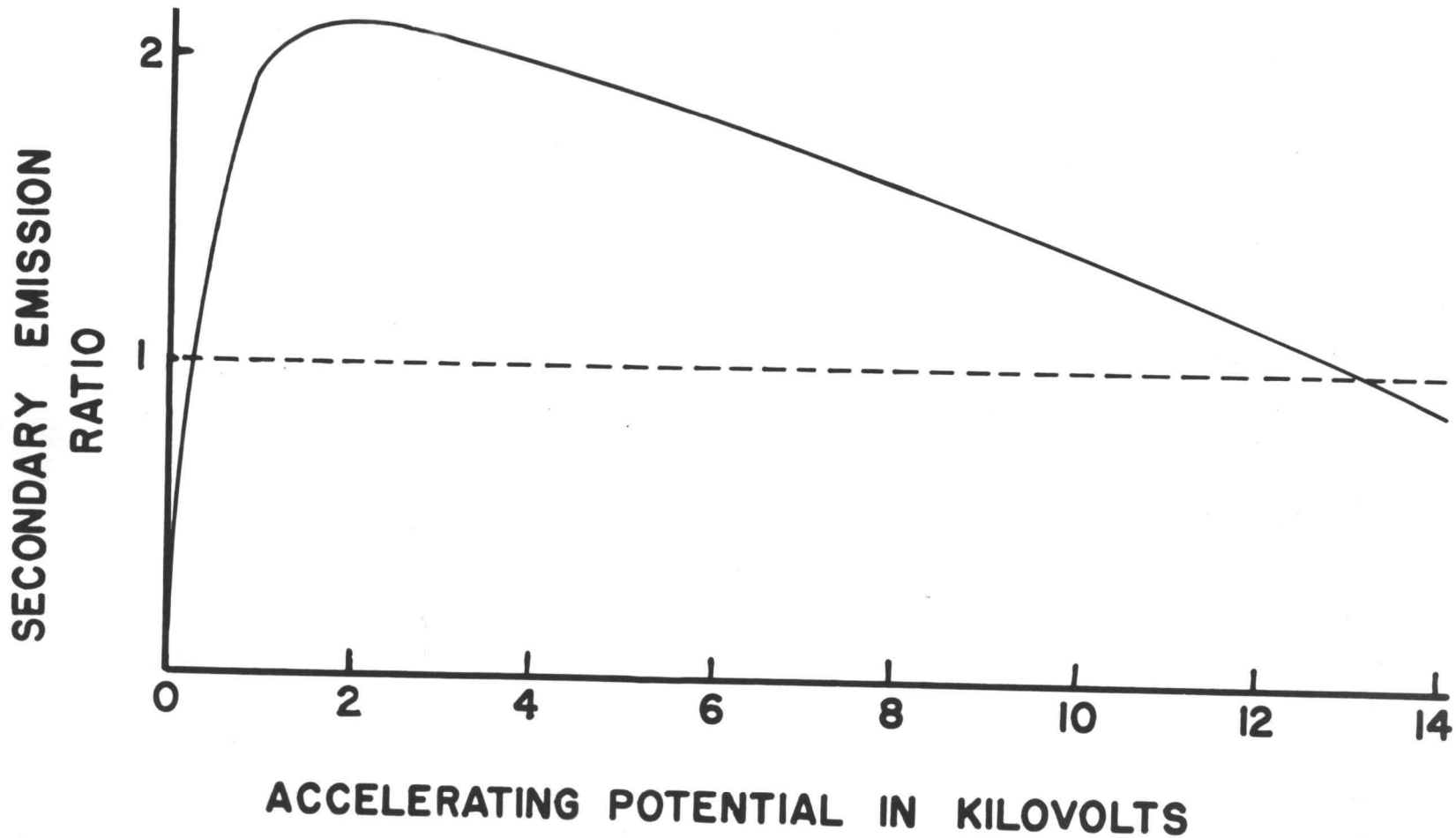


Figure 1. Typical secondary emission characteristics of a hypothetical insulator.

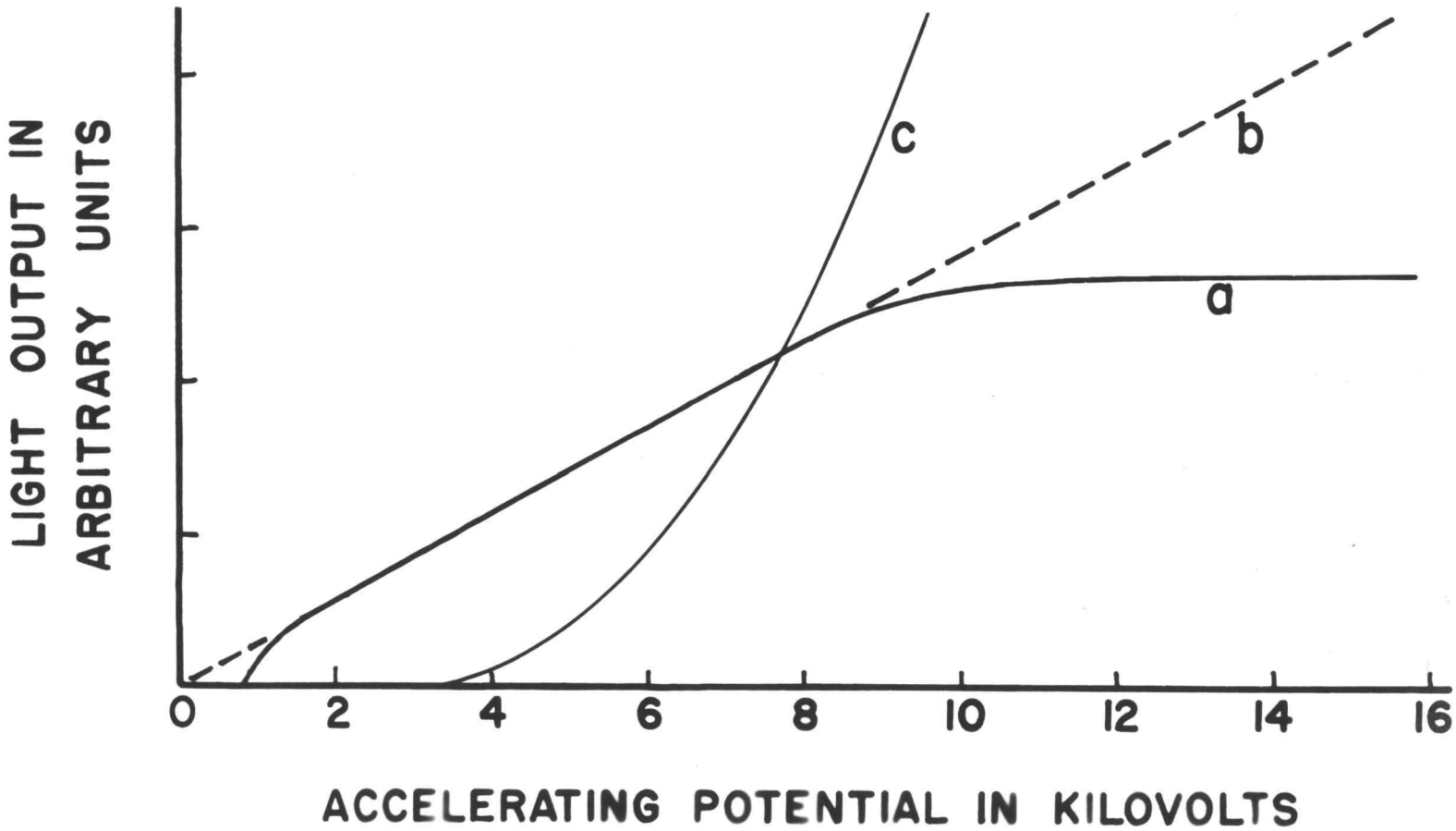


Figure 2. Light output characteristics of a non-aluminized luminescent screen (a); an ideal screen (b); and an aluminized screen (c).

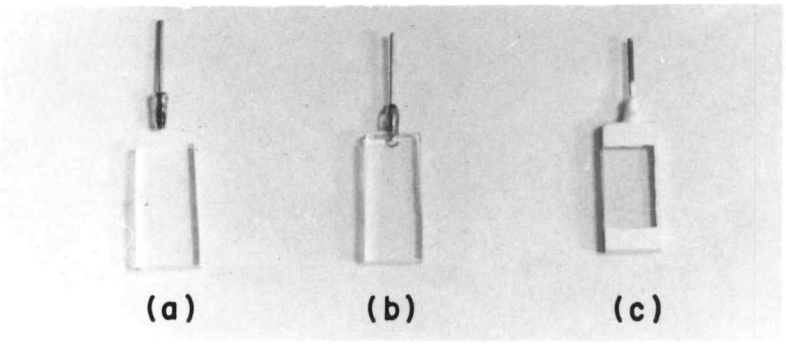
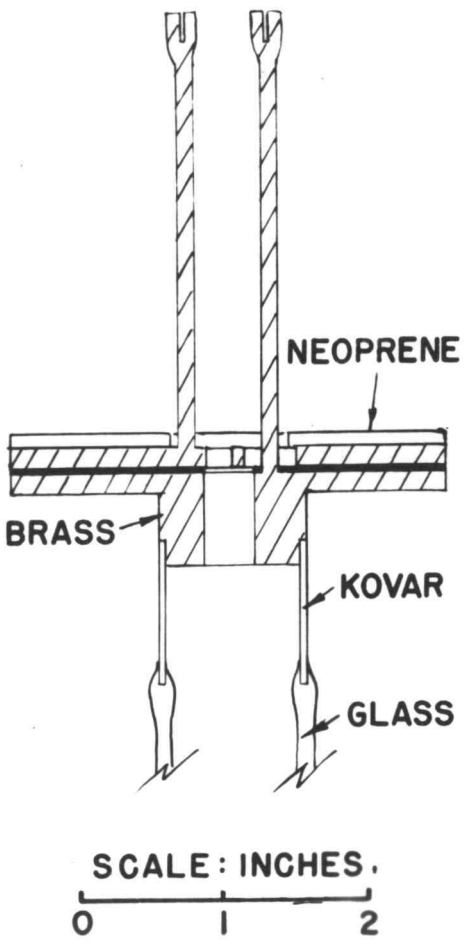


Figure 3. Steps in the construction of a screen carrier.



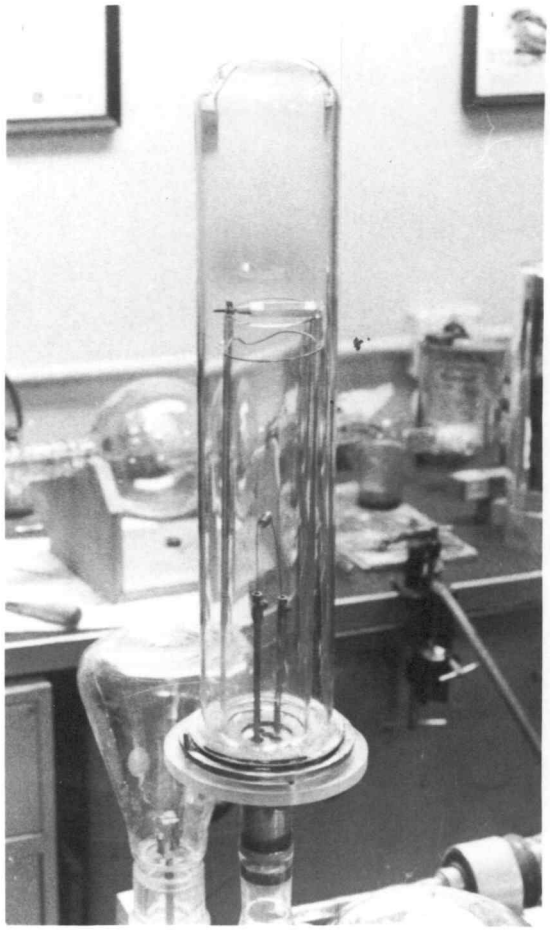


Figure 4a. Scale drawing of the evaporation table.

Figure 4b. Arrangement of components for evaporation of phosphor or aluminum in high vacuum.

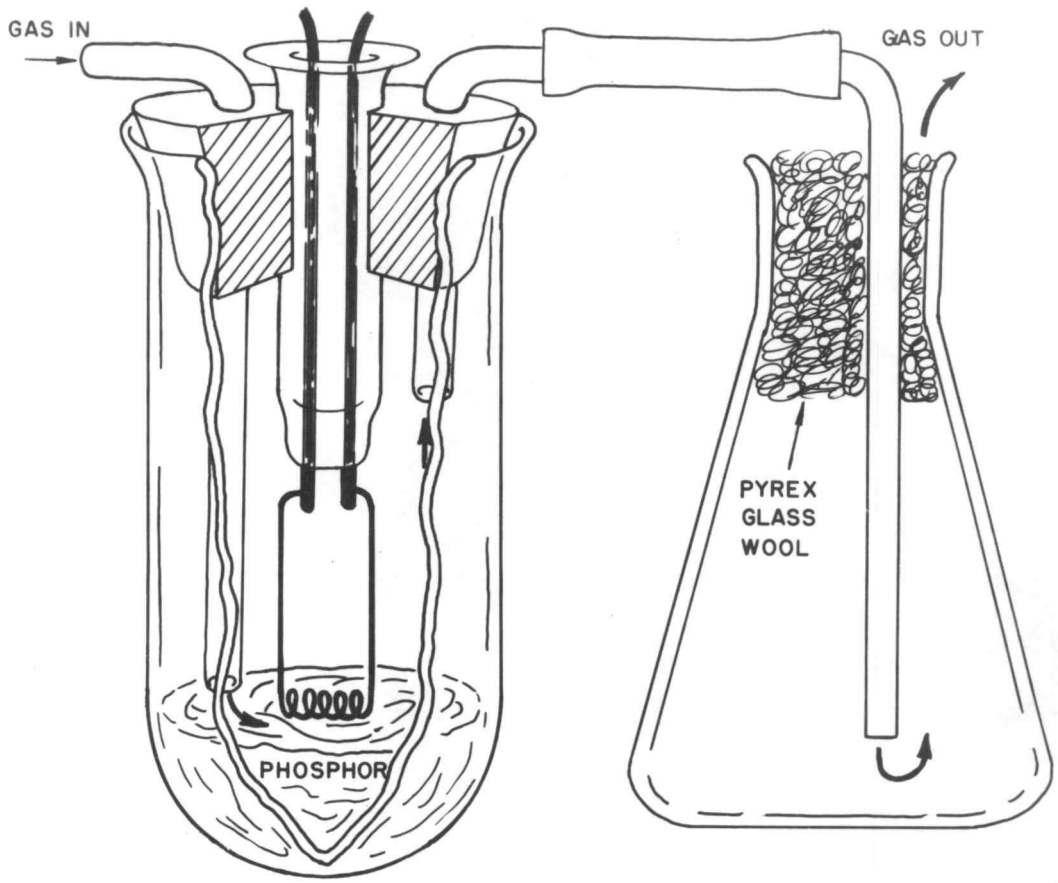
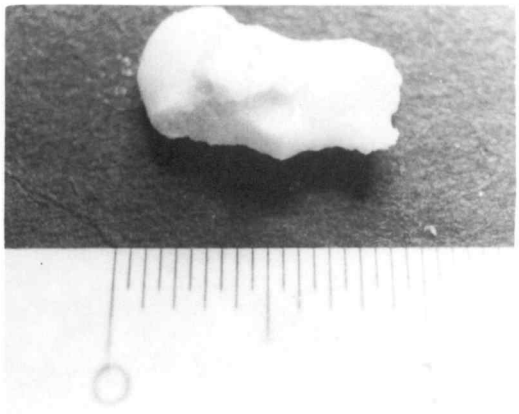


Figure 5. Apparatus for producing solid globules of phosphor for subsequent evaporation.



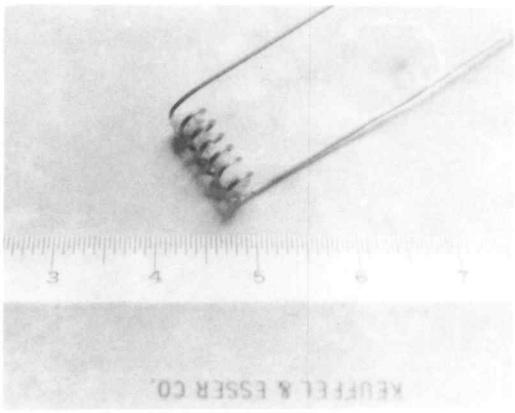


Figure 6a. Solidified globule of manganese-activated zinc fluoride phosphor.

Figure 6b. 20 mil tungsten filament containing tiny bits of phosphor.

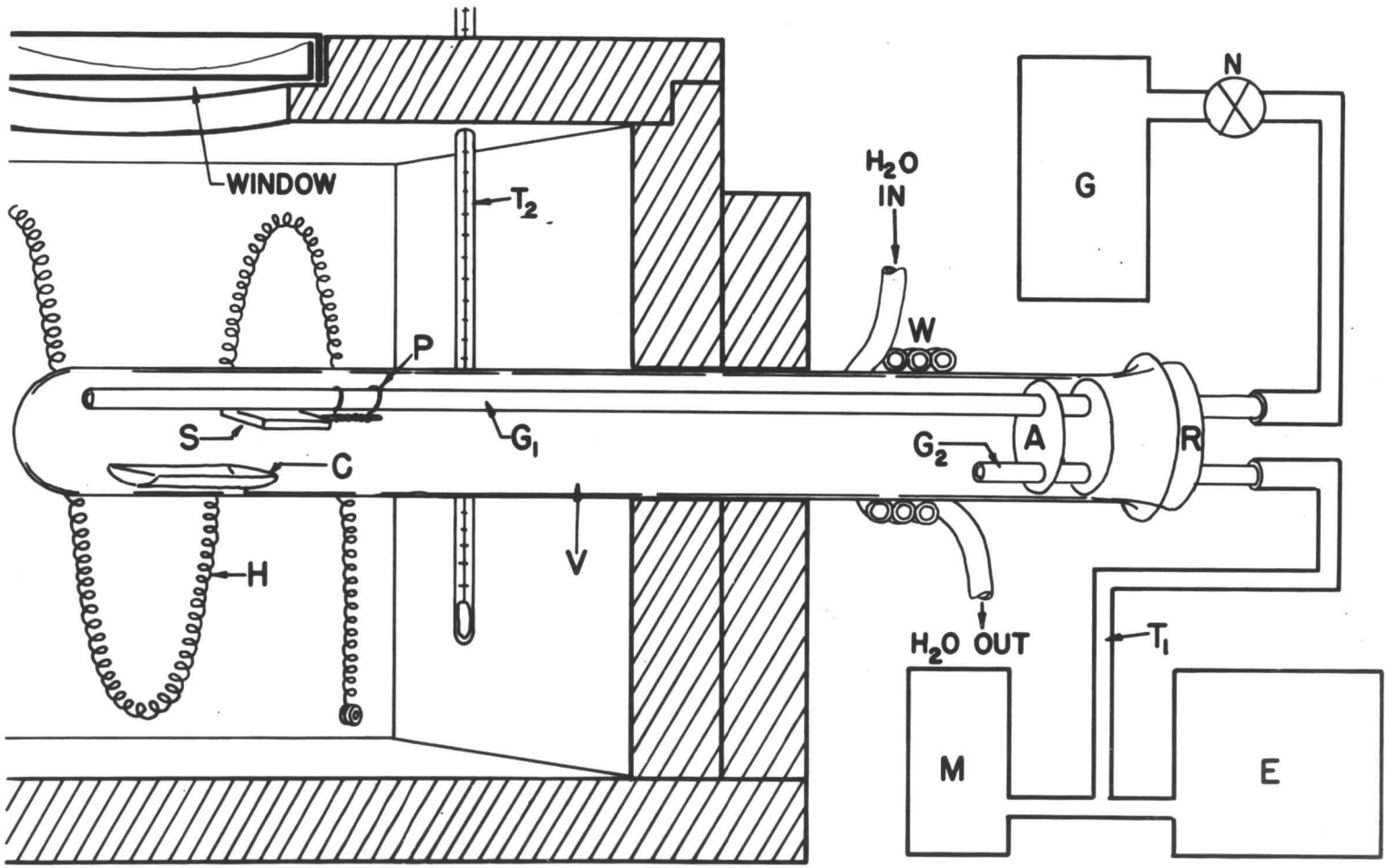
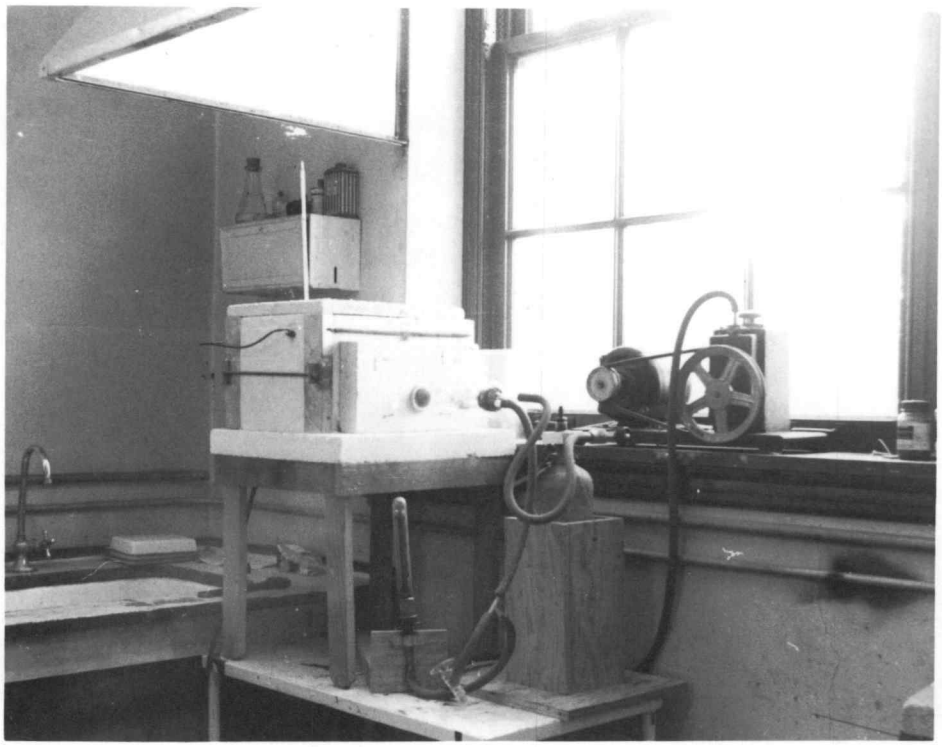


Figure 7. Semi-schematic of the apparatus for vapor phase deposition of thin luminescent screens.



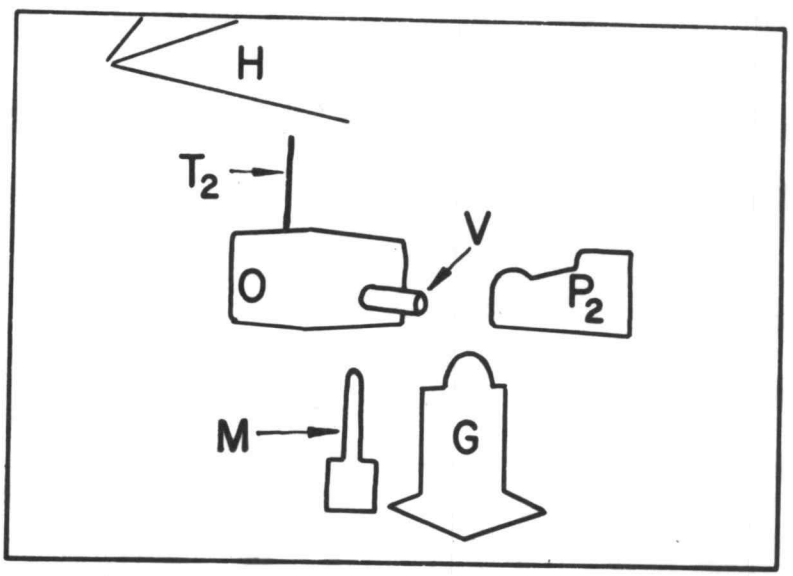


Figure 8. Arrangement of the hood H, oven O, vessel V, thermometer T_2, vacuum pump P_2, manometer M, and hydrogen sulfide container G used for the vapor phase deposition of thin luminescent films.

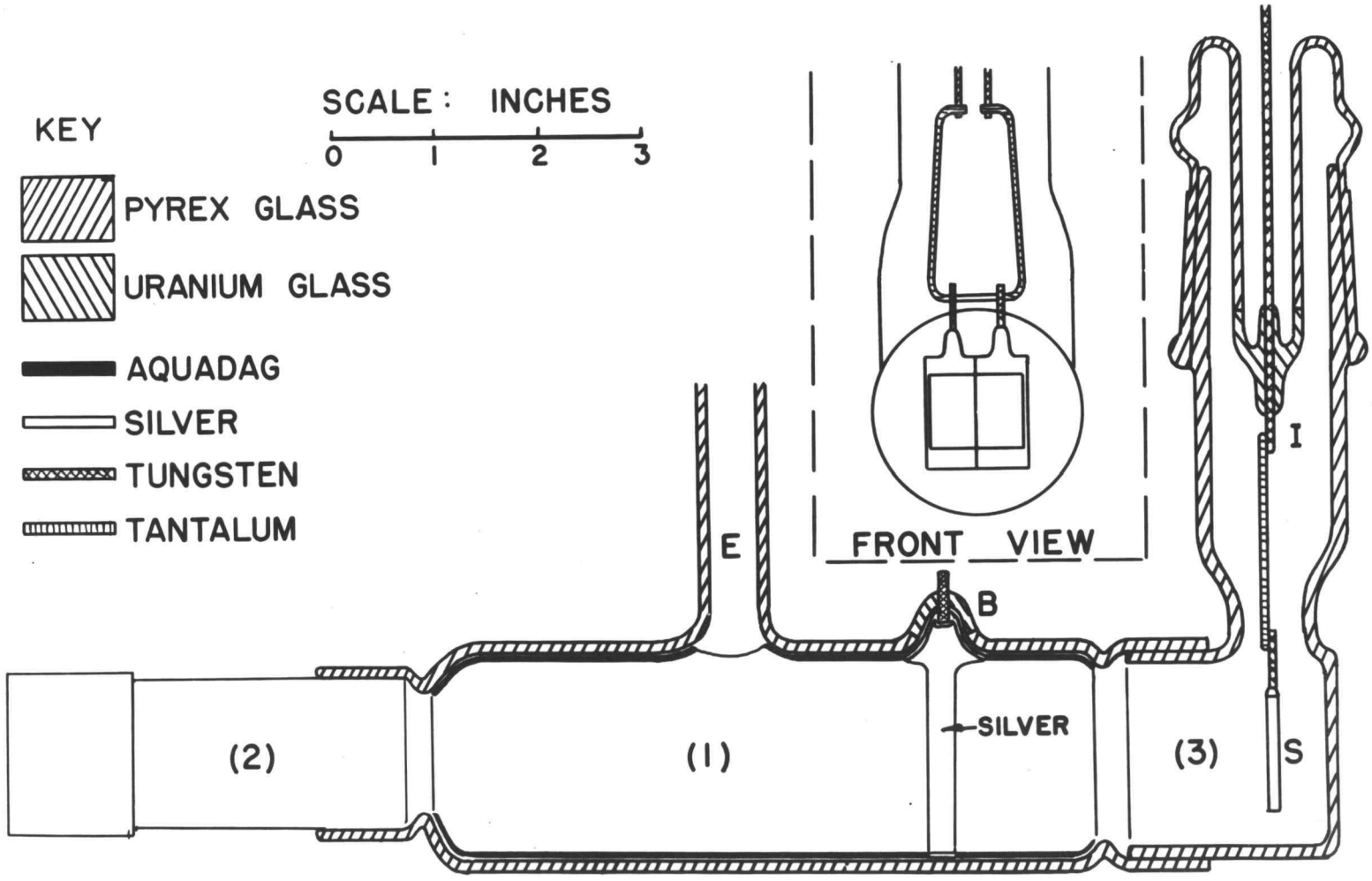
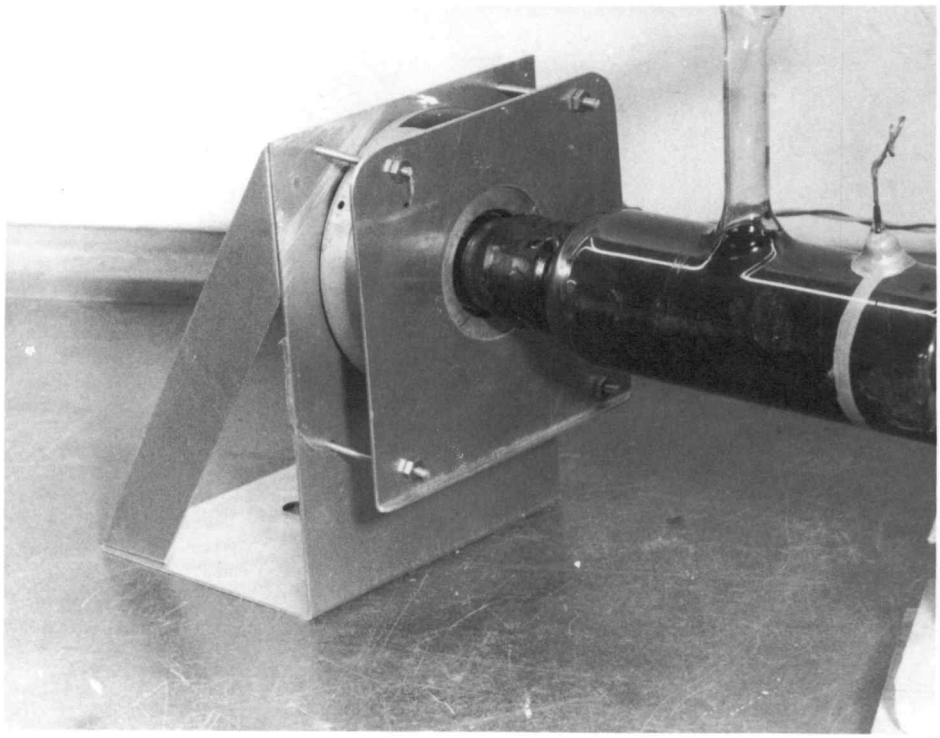


Figure 9. Scale cross-sectional drawing of experimental Tube 1.



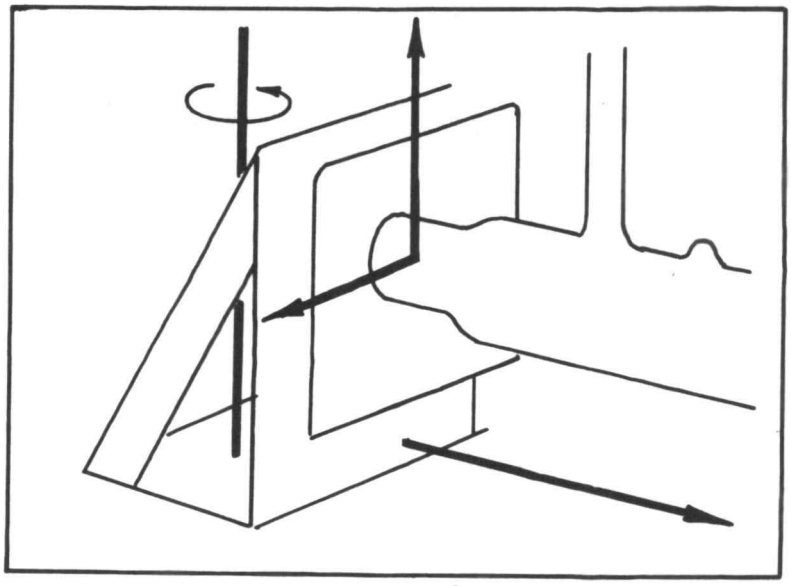
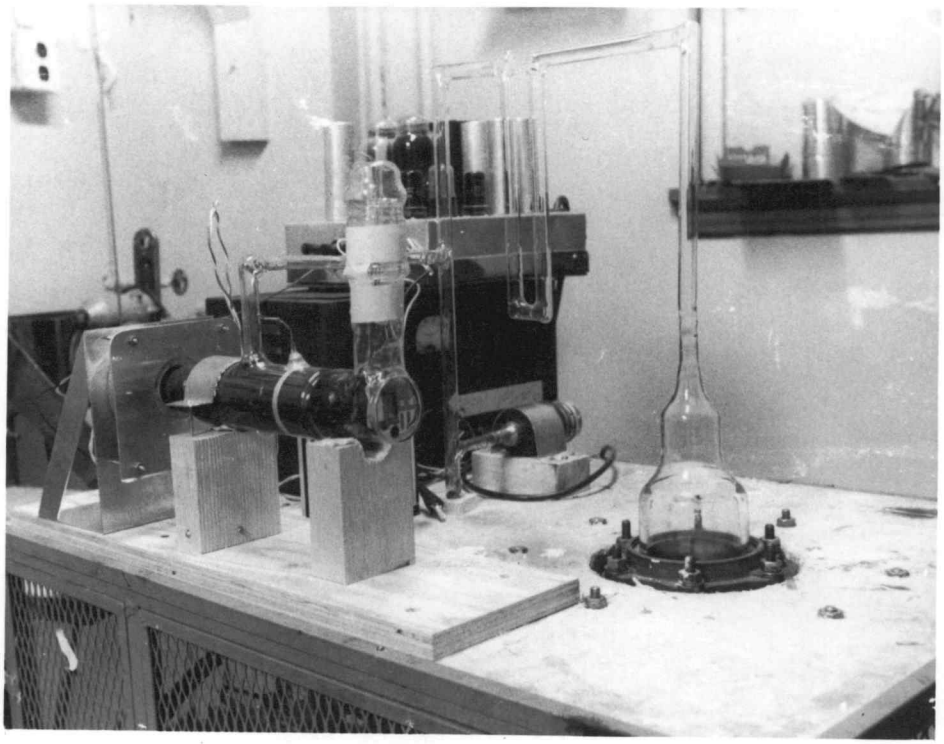


Figure 10. Focusing coil support for Tube 1 and its degrees of motion.



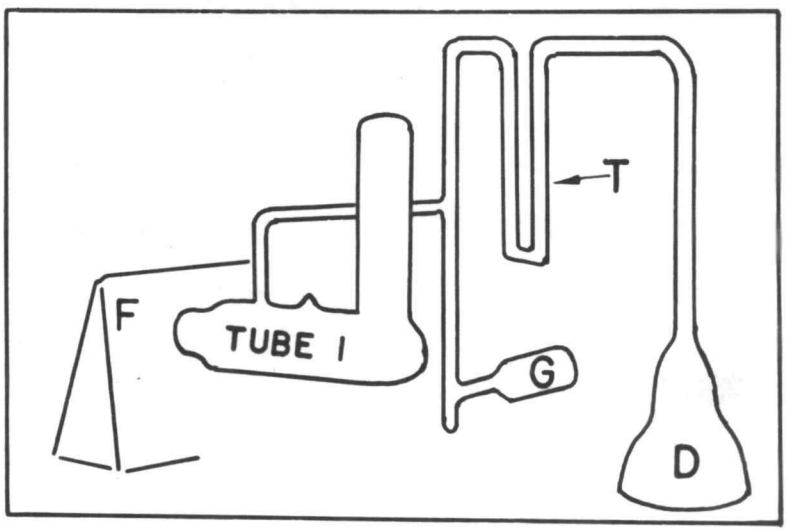


Figure 11. Tube 1 mounted on the vacuum system. The components are: experimental Tube 1; focusing coil F; liquid air trap T; vacuum gauge G; and diffusion pump D.

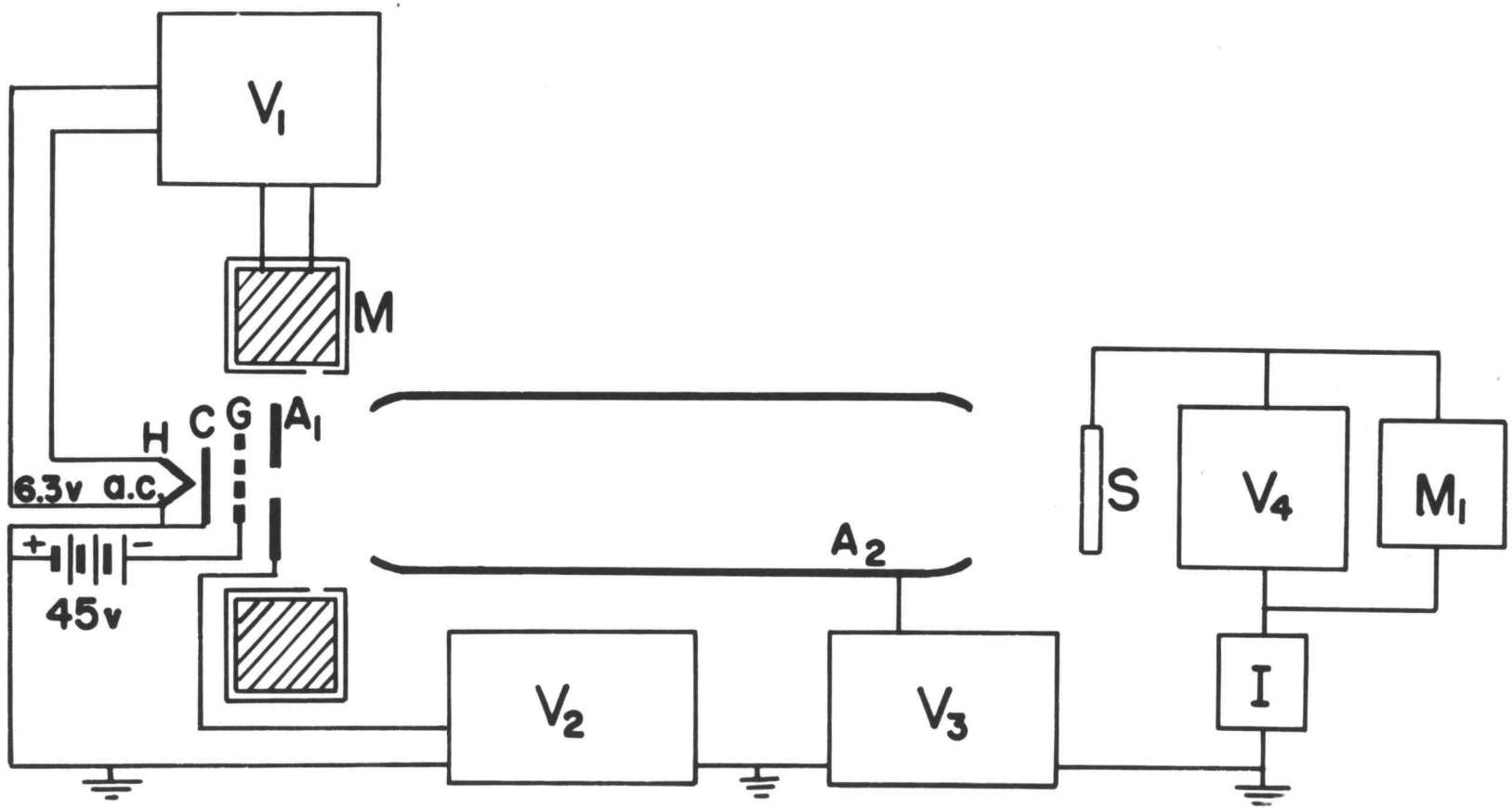


Figure 12. Schematic of the electrical apparatus for the operation of Tube 1.

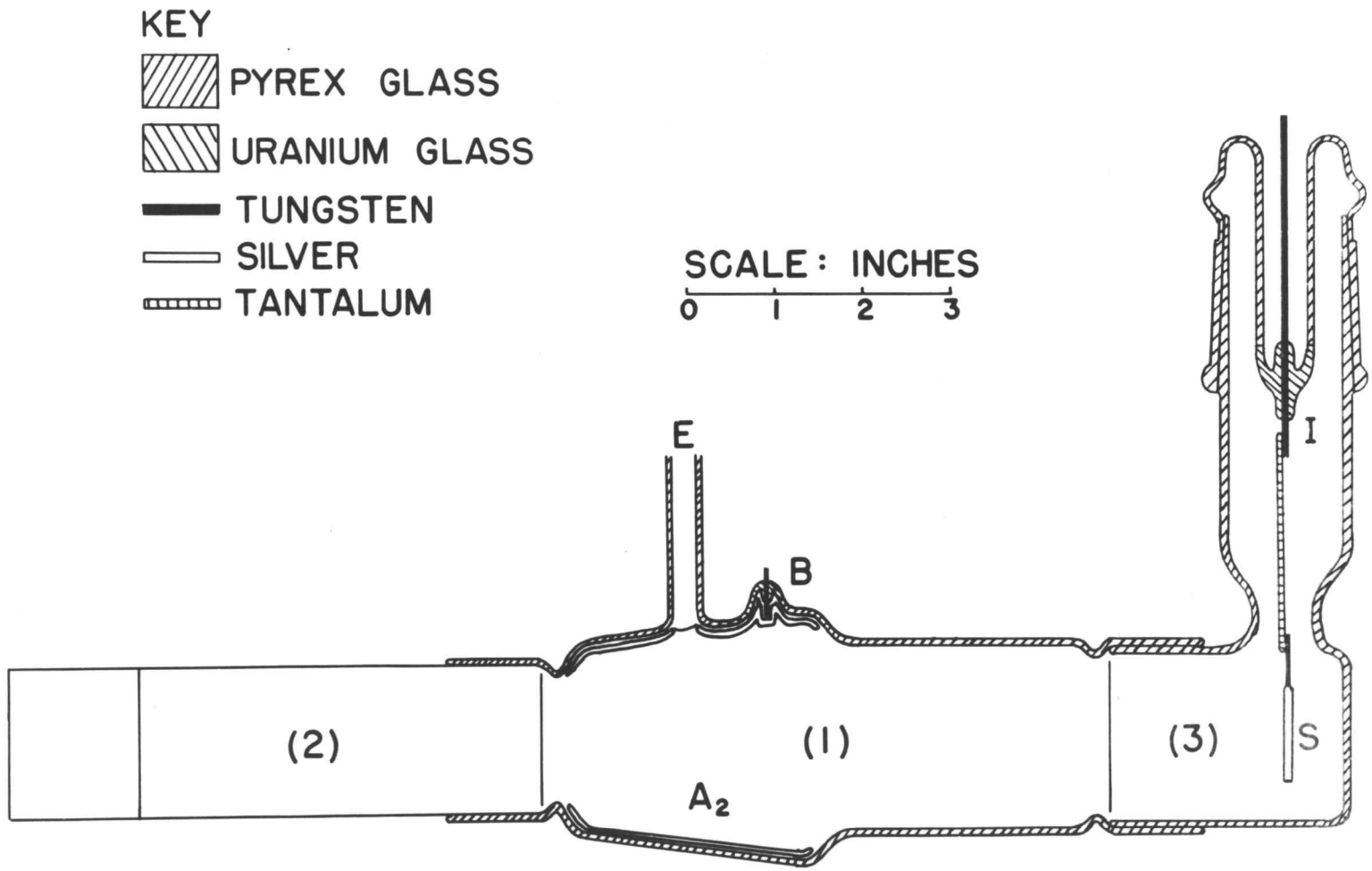
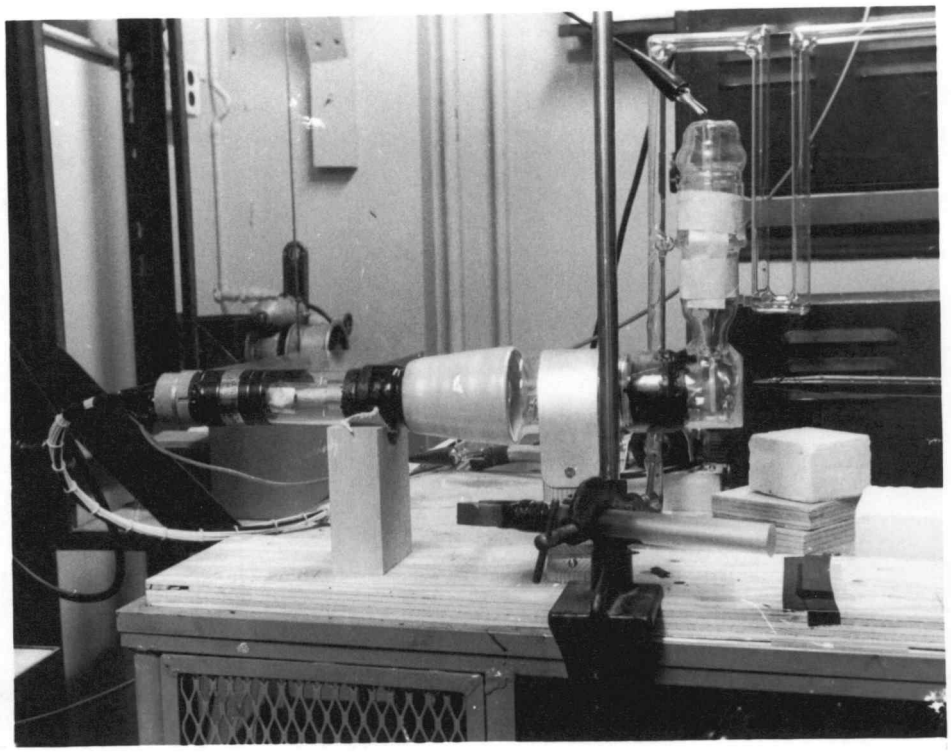


Figure 13. Scale cross-sectional drawing of experimental Tube 2.



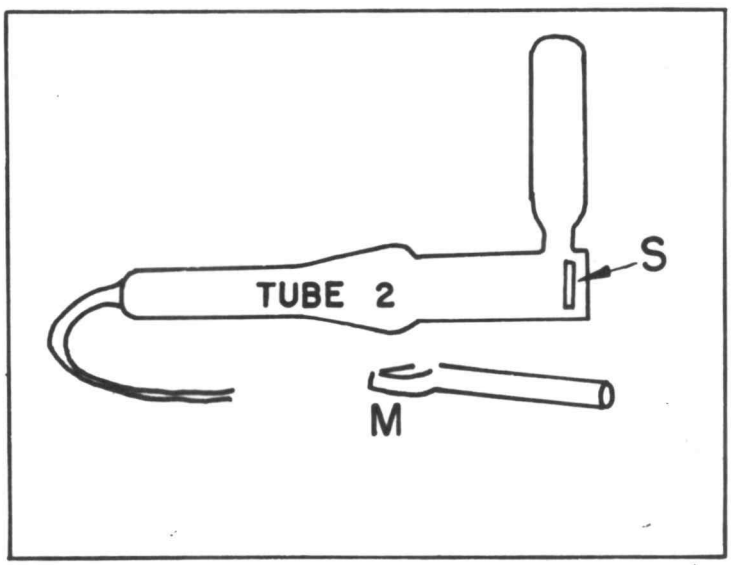


Figure 14. Tube 2 mounted on the vacuum system. Small horseshoe magnet M, used to center the electron beam on the screens S.

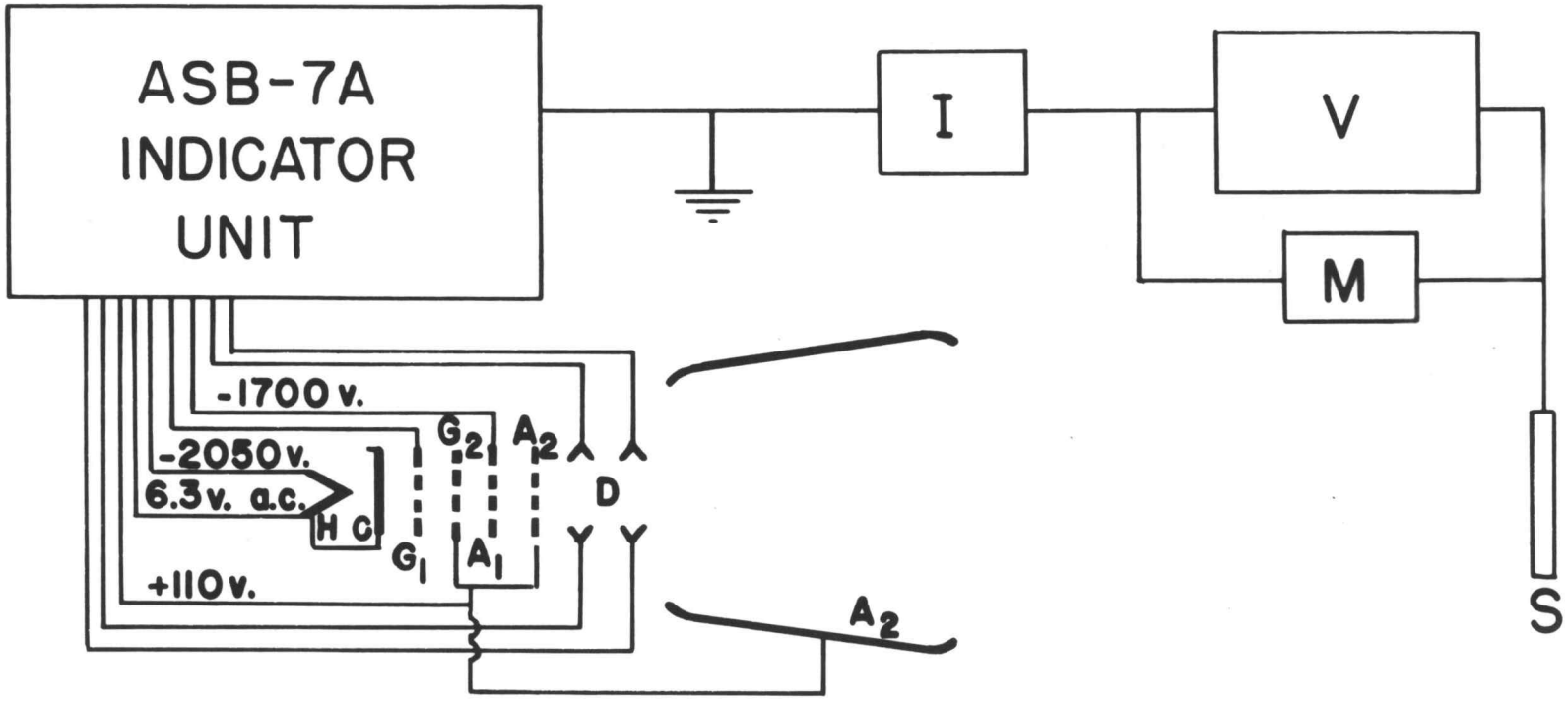
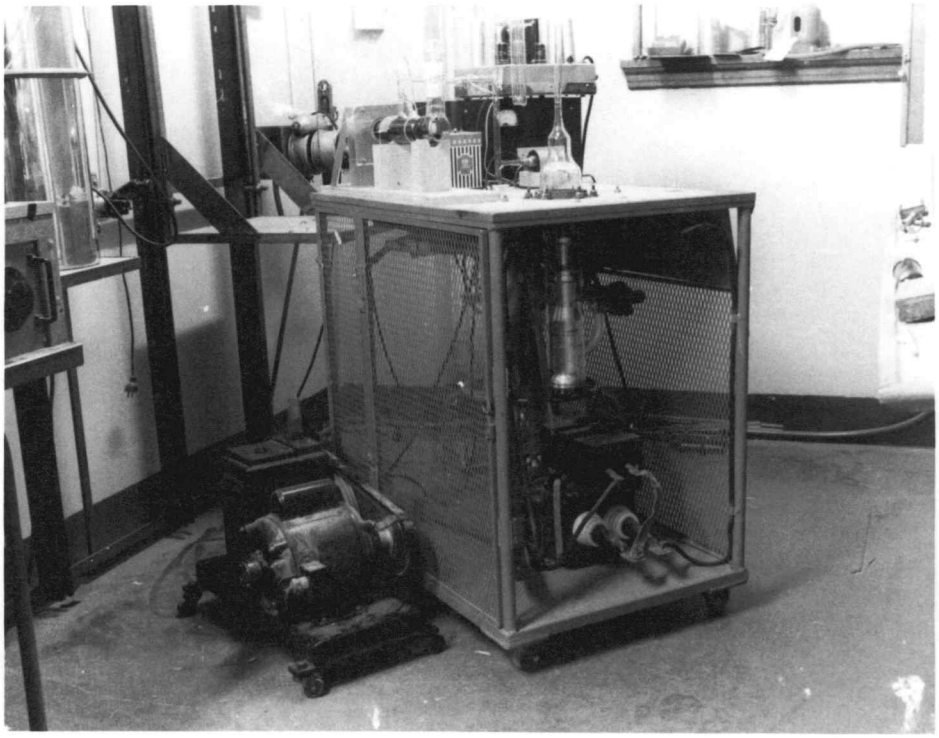


Figure 15. Schematic of the electrical apparatus used in the operation of Tube 2.



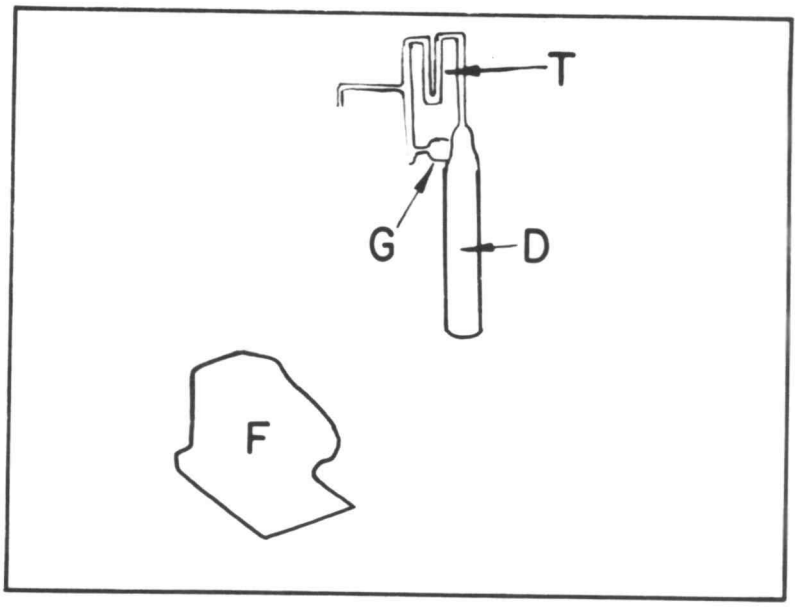
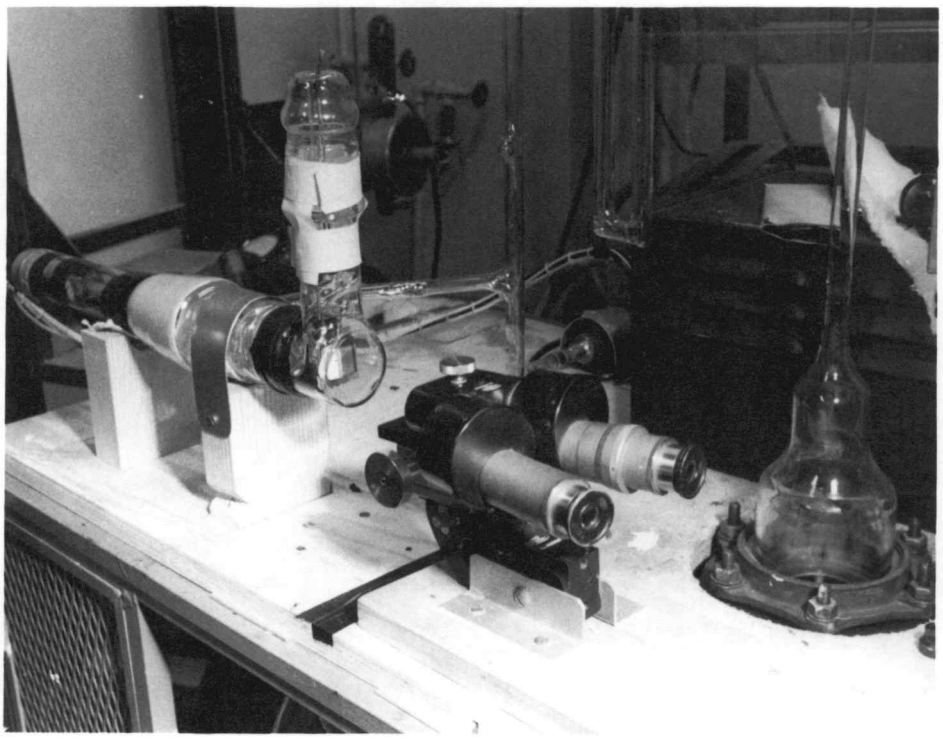


Figure 16. Components of the vacuum system: liquid air trap T, vacuum gauge G, diffusion pump D, and mechanical forepump F.



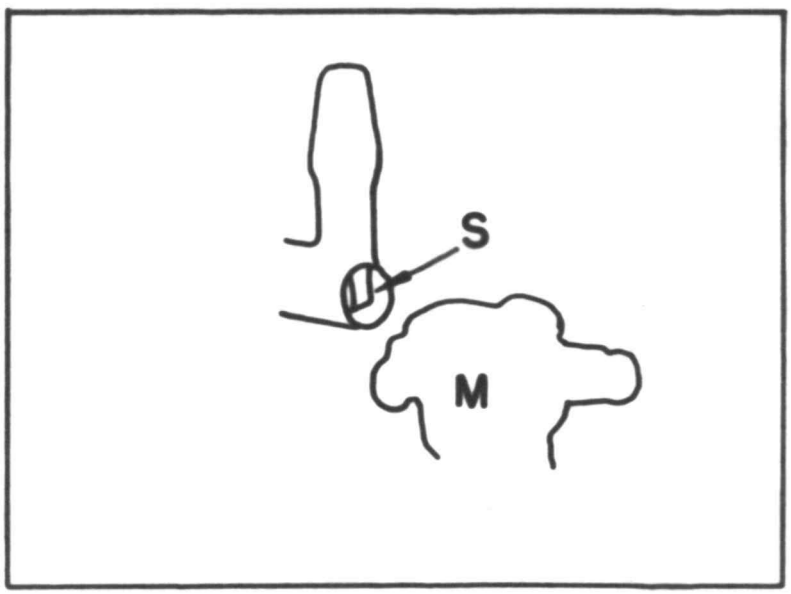


Figure 17. Microscope M, in position for measuring the dimensions of the excited region of screen S.

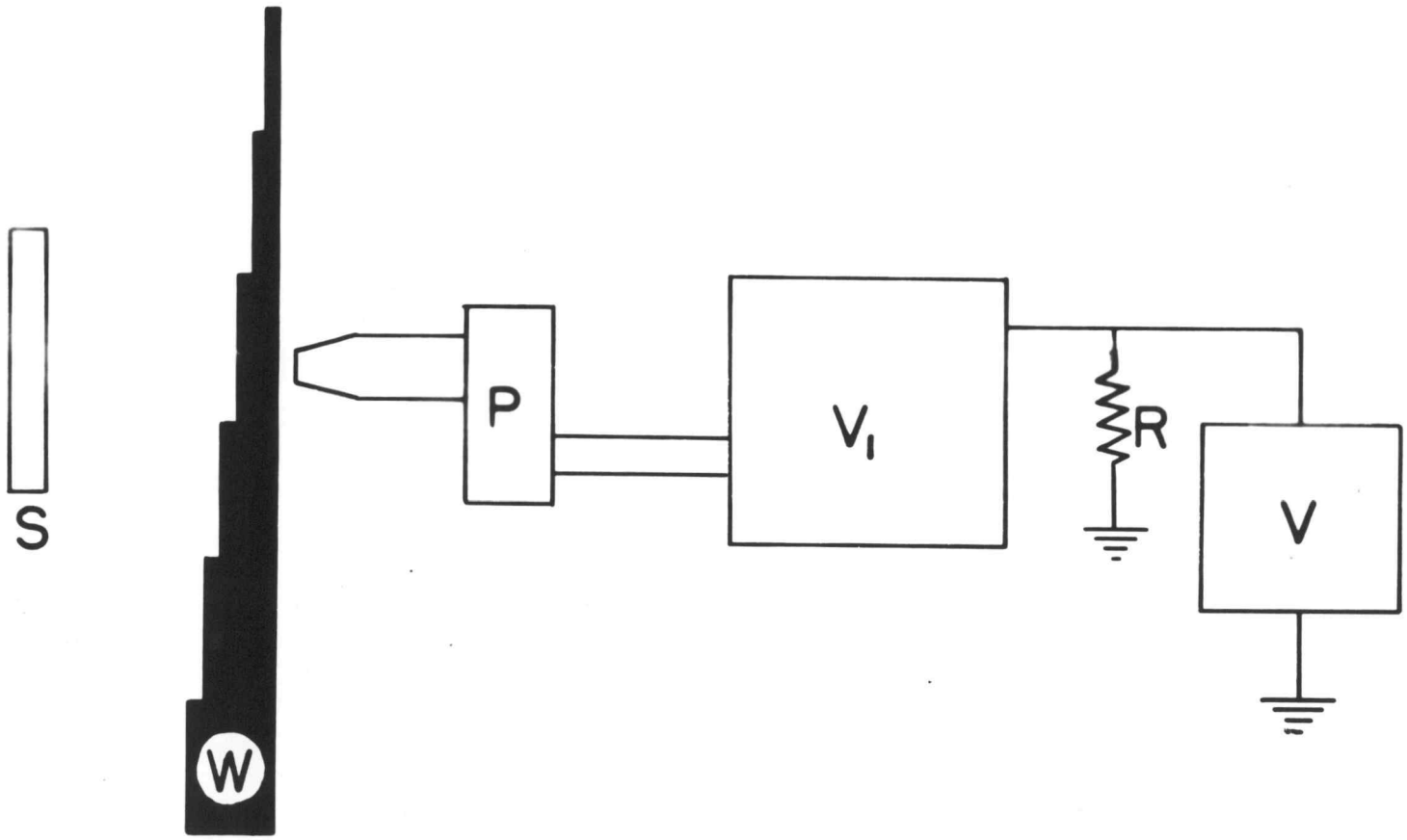
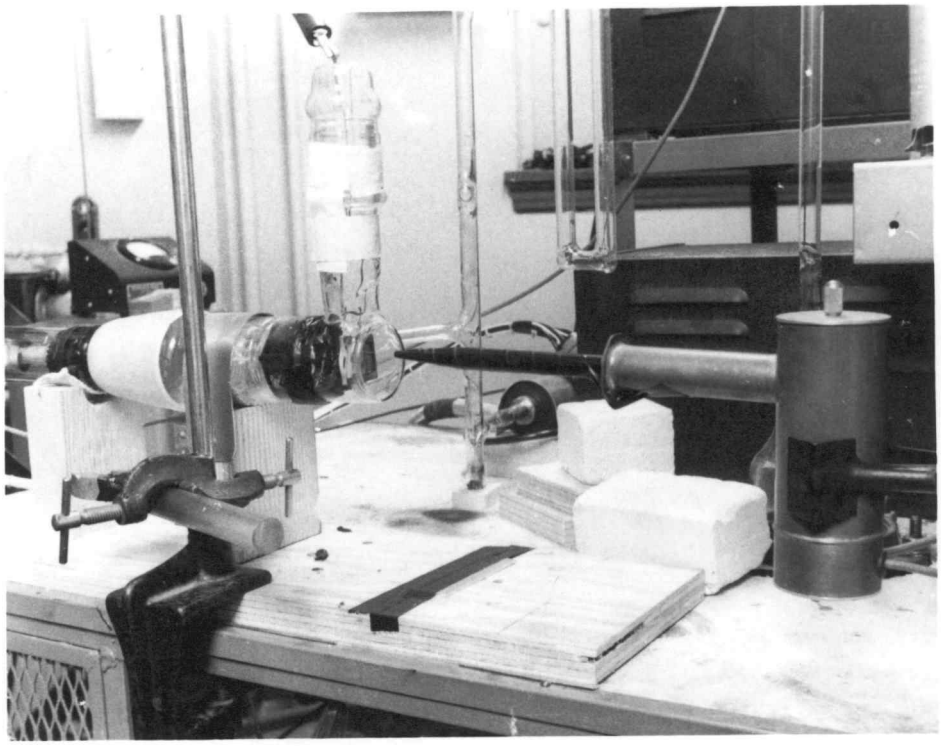


Figure 18. Schematic of the electrical apparatus associated with the measurement of light emitted by the luminescent screens.



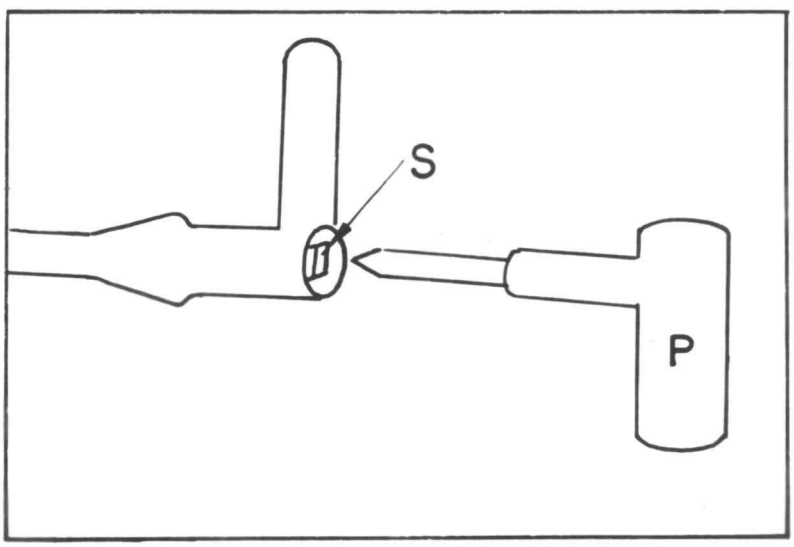
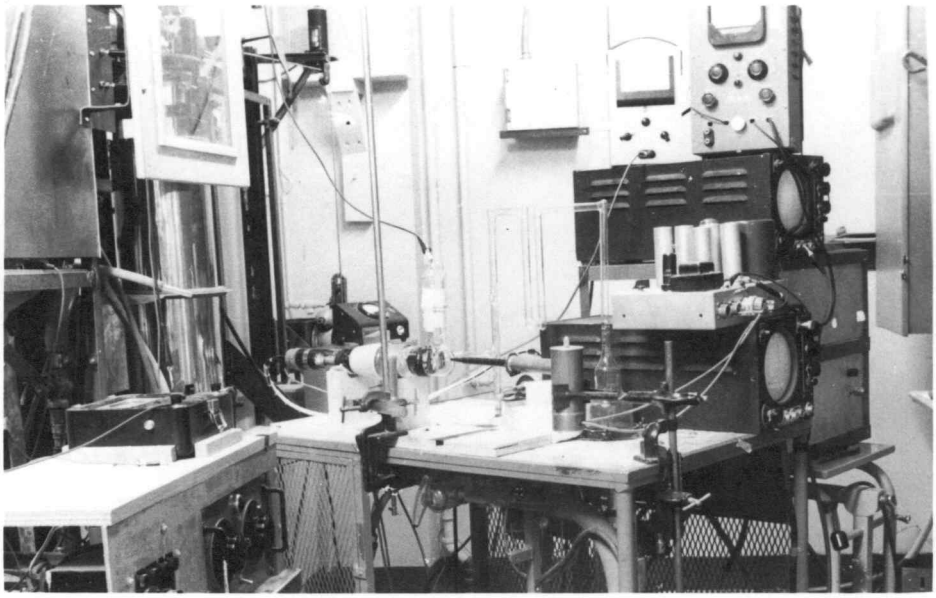


Figure 19. Photomultiplier P, in position for measurement of light emitted from each of the screens S.



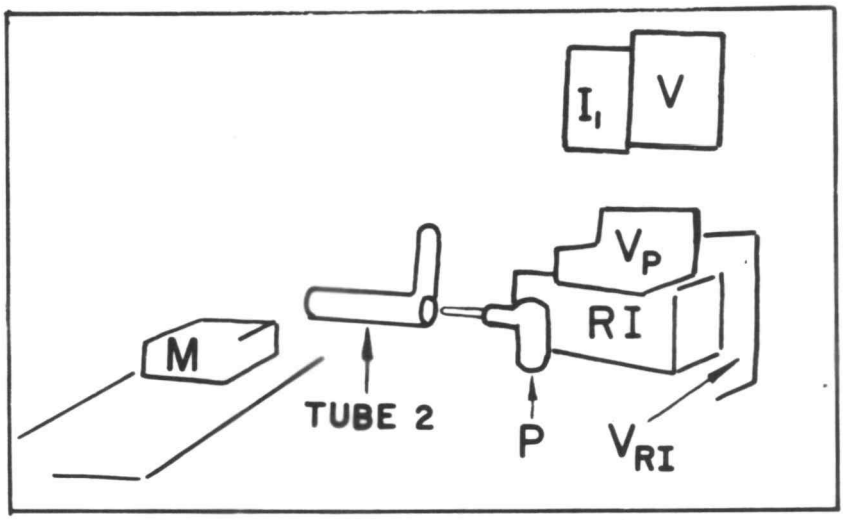


Figure 20. Electronic equipment used in the determination of the characteristics of the thin luminescent screens (Tube 2). The components are: voltmeter M, for measuring screen potential; photomultiplier P; power supply for the photomultiplier V_p; voltmeter V, for measuring the output of the photomultiplier; radar indicator RI; power supply V_{RI}, for the radar indicator; and the current meter I_1, for measurement of screen current.

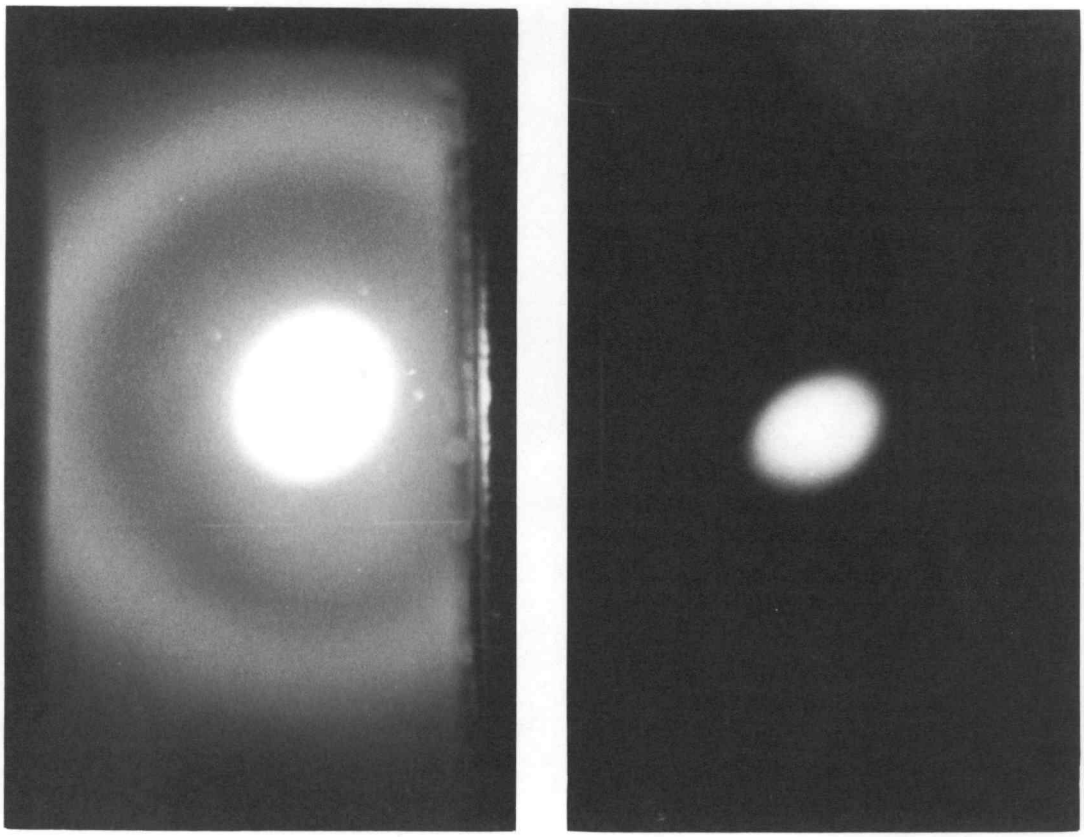


Figure 21. Photographs illustrating the superior local contrast and resolution of the thin, transparent luminescent screen (right) compared to the conventional powdered willemite screen (left). Both screens are in the same tube and the focusing of the electron beam is identical in the two cases.

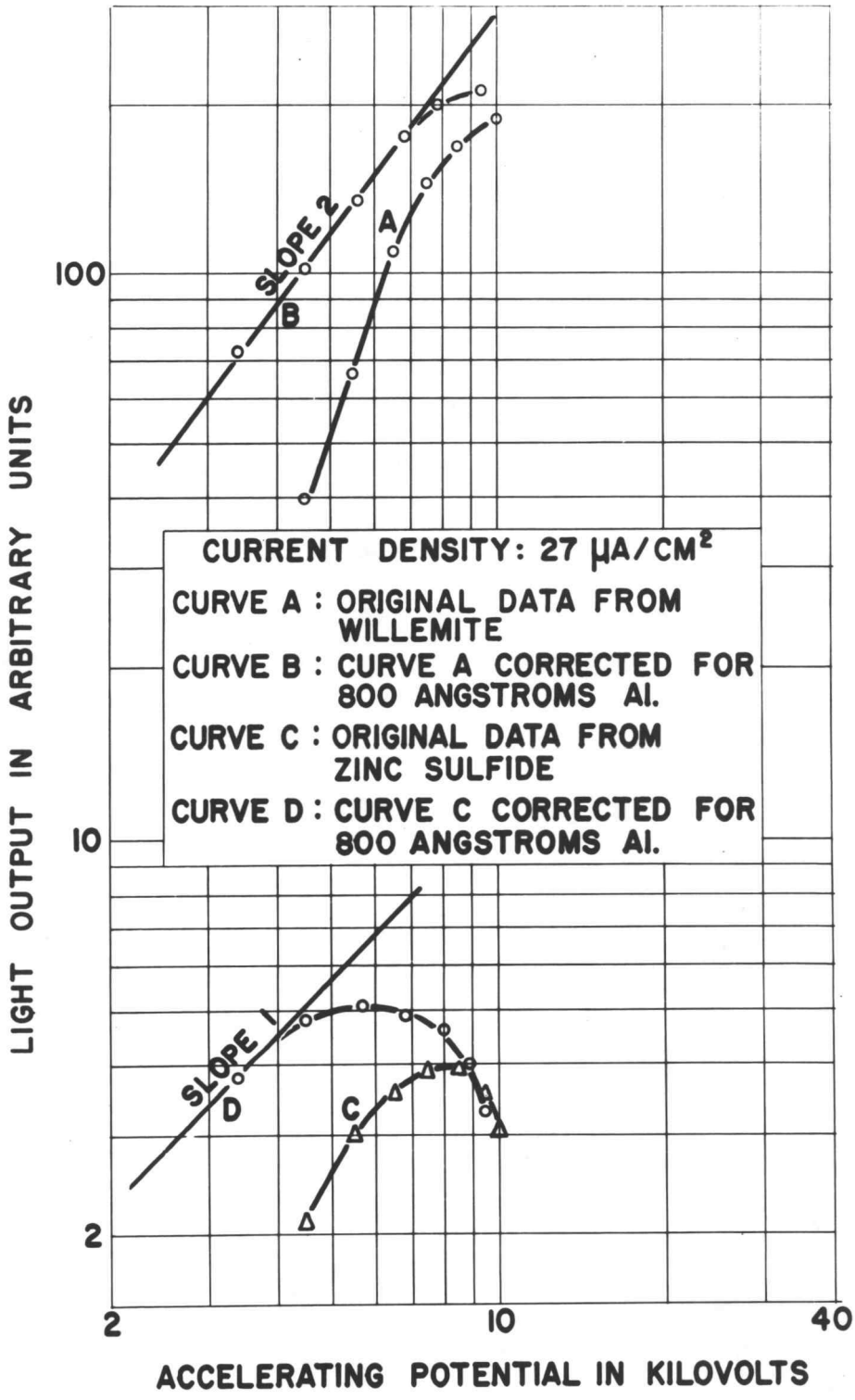


Figure 22. Light output vs. voltage data from the powdered willemite screen and the transparent zinc sulfide screen at a current density of 27 microamperes/cm^2.

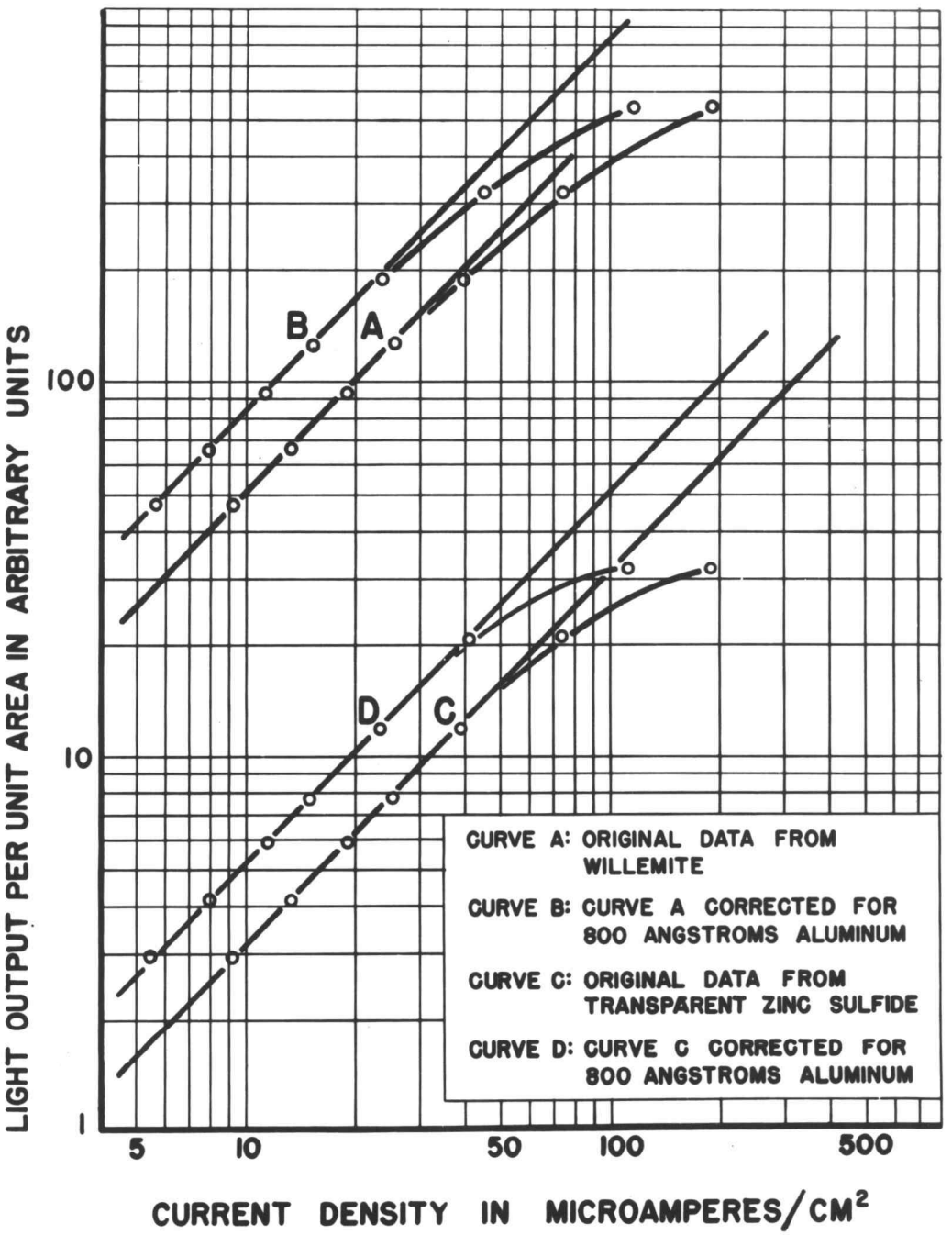


Figure 23. A comparison of the light output/unit area vs. current density data from the powdered willemite screen and the transparent zinc sulfide screen at 5000 volts accelerating potential.

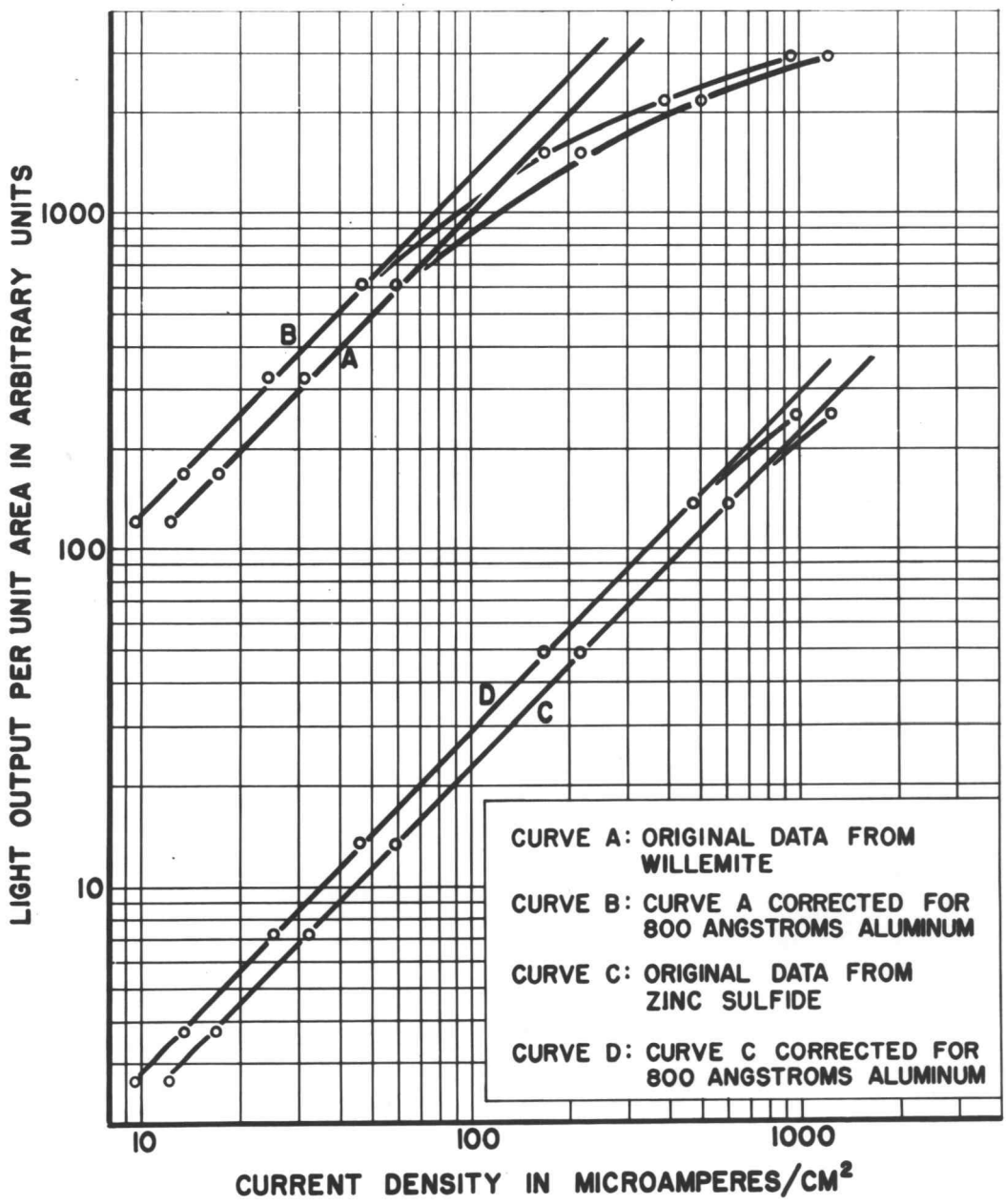


Figure 24. A comparison of the light output/unit area vs. current density data from the powdered willemite screen and the transparent zinc sulfide screen at 7000 volts accelerating potential.

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APPENDIXES

APPENDIX A

The stock solution of willemite lacquer is prepared as follows: 40 grams of phosphor (Appendix C, item 27) is poured into a 1 quart ball mill which is half filled with well rounded 3/4" flint pebbles. 80 cc. of amyl acetate is added and the jar sealed. It is then placed on a device which rotates the jar approximately 15 r.p.m. This operation is continued for a period of 4 hours (to break up aggregates) then the jar is opened and the mixture is poured into a well cleaned flask. An additional 20 cc. amyl acetate is poured into the jar for rinsing. This is then also poured into the flask. After the phosphor has settled, 50 cc. of the original 100 cc. amyl acetate is poured off. 25 cc. of Varniton label varnish (Appendix C, item 28) is added to the contents of the flask and thoroughly mixed by shaking. The phosphor solution is then ready for application.

Flat surfaces of small dimensions are readily handled with this lacquer flow technique, however, it is particularly applicable to spherical and other curved surfaces. A small amount of the lacquer solution (the amount for any given surface is determined by experience) is poured on the surface

to be coated. The surface is then simultaneously rotated and tilted until the surface is evenly coated. Rotation at a slightly inclined angle is continued until the lacquer is dry. Drying may be speeded up by passing a gentle stream of air over the surface.

APPENDIX B

The base plate of the evaporation unit is constructed as follows (see Fig. 4a for scale drawing): two circular pieces of brass 3 inches in diameter, 3/16 inch thick, are sandwiched together. Since the voltage required for heating the filament is only a few volts, a thin sheet of micalex cloth painted on both sides with red Glyptal is sandwiched between the brass plates. This is then placed under a few pounds/in^2 pressure until the glyptal is dry. The edges are then painted with glyptal as a further precautionary measure against air leak through the sandwich. A flat 1/8 inch neoprene plate (with hole in center) serves as the vacuum seal between the upper brass plate and the bell jar. Two posts, which hold the filament, are threaded into the plates; one into the top plate, one into the lower plate. Electrical connection from the power supply is made to these two plates.

A Kovar-to-glass seal is soldered to the lower plate. This is in turn sealed to a ground joint.

This unit fits readily on a general purpose vacuum system in the laboratory.

APPENDIX C

1. Pyrex #7740 Sheet Glass: Stock No. P7160 16"x16"x1/8". Scientific Glass Apparatus Co., Inc. 100 Lakewood Terrace, Bloomfield, New Jersey.
2. Alconox Cleaner: Alconox Inc., Jersey City, New Jersey.
3. Silver Paint: Dupont #4760, E. I. duPont deNemours and Co., Wilmington, Deleware.
4. Detergent: Tide, Proctor and Gamble, Cincinnati, Ohio.
5. Metal Carrier: R. C. A. Part No. 33-B256B; Stock Solution diluted 1 part per 20 parts ethyl acetate.
6. Zinc Fluoride Phosphor: R. C. A. Part No. 33-Z-616 R. C. A. Victor Division, Lancaster, Pennsylvania.
7. Kaylo: Kaylo Division of Owens-Illinois, Toledo 1, Ohio.
8. High Temperature Mercury Thermometer: Borosilicate Glass, No. 397-86, Arthur S. Lapine and Co., 6001 S. Knox Ave., Chicago 29, Illinois.
9. Vacuum Grease: Celvecine, Medium Vacuum Grease, Distillation Products, Inc., Rochester, New York.
10. Hydrogen Sulfide Gas: "D" Cylinder (contains traces of air and water vapor; 99.5% pure). Ohio Chemical and Surgical Equipment Co., Cleveland, Ohio.

11. Needle Valve: No. 2RB285, Hoke Incorporated, South Dean St. and Garrett Place, Englewood, New Jersey.

12. Vacuum Pump: Cenco Pressovac, No. 90550, 600 r.p.m. Catalog J-150. Central Scientific Supplies Co., Main Office and Plant; 1700 Irving Park Road, Chicago 13, Illinois.

13. Chemicals: Zinc Metal (30 mesh) and Manganese Chloride ($MnCl_2 + 4H_2O$), Mallinkrodt Chemical Works, New York, New York.

14. Pliecene Wax: Melts at 80°C. May be heated repeatedly without polymerization. Stock No. 1141, Catalog J-150, Central Scientific Co., same address as Item 12.

15. Aquadag: Colloidal graphite in water. Acheson Colloids Corporation, Port Huron, Michigan.

16. Power Supply: 150 ma, 120-340 volt (regulated) laboratory unit constructed according to circuit published in Amateur's Radio Handbook, 25th ed. p. 245. 1948.

17. Ultrasensitive Microammeter: R. C. A. Type WV-84A, Radio Corporation of America, Harrison, New Jersey.

18. Voltmeter: Weston Mod. 622 microammeter with 20 megohm precision resistor. Weston Electric Instrument Co., Newark, New Jersey.

19. Diffusion Pump: Eimac HV-1, Eitel-McCullough, San Bruno, California.

20. Fore-pump: Megavac, No. 92010, Catalog J-150, Central Scientific Supply Co., same address as Item 12.

21. Vacuum Gauge: Phillips Type PHG-09, Consolidated Vacuum Corporation, Rochester, New York.

22. Vacuum Grease: Apiezon "L" Grease, Metropolitan-Vickers Electrical Co. Ltd., Sold in the U.S.A. by James G. Biddle Co., 1316 Arch St., Philadelphia 7, Pa.

23. Microscope: Olympus Binocular Microscope OlC No. 100006, Transpacific Import and Export Co., 116 N. E. 136th Ave., Portland, Oregon.

24. Photomultiplier: R.C.A. Type 931-A, Radio Corporation of America, Harrison, New Jersey.

25. Vacuum Tube Voltmeter: Model 410A, Hewlett-Packard, Palo Alto, California.

26. Density Step Wedge: Eastman Kodak Calibrated Photographic Step Tablet No. 2. Contains 21 steps covering the density range 0 to approximately 3.0. Eastman Kodak Co., Rochester, New York.

27. Willemite Phosphor: Sylvania #2281 Standard Green. The Sylvania Electric Products, Inc., Towanda, Pa.

28. Varniton: Label Varnish #V-21, The Varniton Company, 416 N. Varney St., Burbank, California.